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SOIL MOISTURE REGIME AND SALINITY ON A TAILINGS SAND STORAGE FACILITY

by

Crystal L.A. Chaikowsky

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in

WATER AND LAND RESOURCES

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **SOIL MOISTURE REGIME AND SALINITY ON A TAILINGS SAND STORAGE FACILITY** submitted by **Crystal L.A. Chaikowsky** in partial fulfillment of the requirements for the degree of **Master of Science** in **Water and Land Resources**.

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ABSTRACT

The Southwest Sand Storage Facility (SWSS) is a 25 km^2 tailings sand facility in Alberta's Athabasca oil sands. Revegetation of this structure has been delayed due to concerns of waterlogging and increasing salinity. This study involved monitoring soil moisture and chemistry on one section of the SWSS to examine the variability in soil moisture (spatial, temporal) and the degree of salinization in the topsoil.

The root zone is not currently threatened by saturation or salinity/sodicity. Dry areas were more prominent than wet areas on site. The soil profile, topsoil directly over tailings sand, contains a textural discontinuity that acts as somewhat of a barrier to water flow. This caused moisture above the interface to gradually increase and moisture in the tailings sand to stay consistently low over time. Salinity coincided with soil moisture on site, with greater moisture and salinity at depth in the tailings sand.

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1.0 INTRODUCTION

As the human population increases, so does the need for the energy to sustain it. This places demands on the oil and gas industry to expand, and in the end creates issues of how we will 'rebuild' the environment. One such issue is the formation and reclamation of tailings dams (also referred to as tailings impoundments or tailings storage facilities), designed to house the 'leftovers' from the oil extraction process or other mining operations.

A tailing sand storage facility is essentially a large receptacle for tailings sand, designed with terraced or 'benched' side slopes to promote overall stability of the structure. Tailings are a by-product of the oil sand extraction process, containing a combination of coarse sand with water, fine silt, clay particles and some residual hydrocarbons, all of which are naturally found in the oil sands deposits (Syncrude Canada Ltd. 2001b). In addition to these constituents, chlorides, sulphates and sodium from the oil extraction process are found in this tailing sand/process water slurry. This sand rich slurry (typically 80% sand) is transported via pipelines from the extraction plant to the deposition area, a tailings storage facility. Tailings are different from naturally occurring soils in that the density and strength of materials within a tailings structure are initially low and increase relatively slowly with time (Jewell 1998). Therefore the tailings 'dam' is made of tailings material itself. Such a structure is normally raised sequentially over a period of years instead of being initially constructed to completion (WISE Uranium Project, 2001).

The ultimate goal of reclamation of a tailing sand storage facility is a landscape equivalent to the premining or natural state. This generally includes 'capping' the tailing sand structure with a material that can sustain biological growth (for example, mineral and/or organic topsoil), introducing native vegetative species, and supervising/managing the health and viability of the system. As stated by Blight (1998), a rehabilitated tailings structure should be "a stable landform that blends into

its surroundings"; it should only require minimal maintenance and have an end land use that is acceptable to the surrounding community.

Some concerns associated with tailing sand impoundments are water table formation, capillary rise, leaching, seepage and erosion, and the possibility of transport of tailing constituents (for example, metals, hydrocarbons, salts) by way of these mechanisms (Barth 1986). With the existence of such processes on or within a tailings impoundment, tailing constituents may contaminate areas beyond the impoundment or pose concerns for reclamation of the tailings sand impoundment itself. Balkau (1998) suggested the following measures for successfully resolving environmental issues in tailings management: (i) know the environmental conditions, (ii) use multi-objective planning, (iii) closely supervise construction and operations, and (iv) ensure ongoing monitoring after closure of the structure.

1.1 Background

Depending on the climatic regime of the area and the operating conditions, tailings storage systems may generate either a water surplus or deficit (Blight 1998). The development of high water tables, or a nearly saturated root zone, raises concerns as to whether or not vegetation can survive. In the same manner, the identification of low soil moisture levels also raises concerns of vegetation viability. In this respect, the occurrence of either low or high soil moisture conditions may threaten reclamation feasibility; especially efforts to revegetate the facility. However, it seems that few studies, if any, have been dedicated to addressing soil moisture as a dependent variable in the reclamation feasibility of a tailing sand storage facility.

Salinization of a tailings sand storage structure can also affect reclamation success, and waterlogging and salinity often go hand-in-hand. Salts occur in the process water from mineral or hydrocarbon extraction, and are therefore added to the tailings impoundment along with the tailings slurry. Dissolved salts are then transported within the structure and may accumulate in surface areas as water evaporates. Root

zone salinity and/or sodicity can adversely affect the revegetation of reclaimed areas, as well as the productivity of natural agricultural and forested areas.

1.1.1 Revegetation

The revegetation of a tailings sand storage facility is an essential step in the reclamation process. While a vegetation cover provides aesthetic appeal for the desired end land use, revegetation is primarily used to increase structure stability, reduce surface runoff and erosion, and it participates in the structure's hydrological, chemical, and biogeochemical regimes. The vegetation of a tailings sand storage facility essentially becomes a protective, neutralizing, pollution-controlling device, which is natural and remarkably effective (Leroy 1973). Species diversity is desirable in a reclamation program to encourage soil stabilization at different depths, and to perform functions such as nitrogen fixation (Curtis et al. 1980). Although vegetation can act to diminish some the impacts of tailings disposal, it can also be overcome by the processes at work on the structure; namely the hydrological and chemical regimes. A possible environmental problem area, in respect to vegetation and tailings impoundments, is the reduction of surface or groundwater quality by chemicals that may adversely affect vegetation (Hardwood 1979). Subsequently, if vegetation is unable to grow and a large area is devoid of significant vegetation cover, air quality may be reduced as a result of dust, the microclimate could be altered, and aesthetic quality would be reduced (Hardwood 1979).

1.1.2 Salinity and Waterlogging

Salinization and the accumulation of salts in the root zone may affect vegetation by slowing growth, reducing yields, and can even cause the demise of vegetation (Steppuhn et al. 2000). In this respect, salts can: (i) decrease the osmotic potential of the soil solution, thereby making water less available to plants, (ii) impose direct toxicity on plants as ions (boron, chloride, and sodium for example) accumulate in the plant tissue, and (iii) affect nutrient uptake and translocation within the plant (National Research Council 1993). Salts can also adversely affect soil structure, as

sodium can cause clay dispersion and soil crust formation, subsequently reducing the movement of air and water, and possibly affecting the infiltration and hydraulic conductivity of the soil (Shainberg and Letey 1984).

Waterlogging causes poor aeration in the root zone, which deprives plants of oxygen and may reduce plant growth or even result in the death of plants (National Research Council 1993). Decreased root growth and shallow rooting are effects that have been linked to agricultural crops and trees exposed to waterlogged conditions (Grable 1966; Rowe and Bearsell 1973). For plants that are not salt-tolerant, waterlogging enhances the net uptake of sodium and chloride to the shoots, which can have adverse effects on shoot growth and yield in the long term (Barrett-Lennard 1986). This would have implications for vegetation growing under both saline and wet soil conditions.

There is evidence in the literature of high water tables or saturated conditions, and the occurrence of seepage, in tailings dams or impoundments. Investigations of the Olympic Dam deposit, located in a copper, uranium, gold and silver mine in the far north of South Australia, discovered a localized elevation in the water table, which was attributed to seepage from the system (WMC Resources Ltd. 2002). It was concluded, however, that the seepage had no adverse impact on the surrounding environment.

Scott and Lo (1992) investigated surface and groundwater quality surrounding the Highland Valley tailings storage facility, located at the Highland Valley Copper mine in Logan Lake, British Columbia. Tailings deposition seemed to have little effect on the water quality, which was monitored in wells surrounding the structure, however, nominal seepage from the tailings impoundment was evident.

Al and Blowes (1999) conducted a study on the hydrogeology of a tailings impoundment at the Kidd Creek copper-zinc sulphide mine, Ontario, Canada. They found the presence of a thick capillary fringe, supported by the uniform grain-size

distribution of the tailings, which causes rapid increases in the water table following precipitation events. This study was conducted before the capping of the impoundment. Moisture content profiles indicated that the tailings were saturated to within 0.3 – 0.4 m of the surface in late July (Al and Blowes 1999). These conditions favoured evaporation from the tailings surface, and resulted in the precipitation of solutes (calcium and sodium sulphate salts) on the surface.

Another limitation of wet soils is decreased stability. Water weakens the bonds between clay particles, and can give the buoyancy to separate sand particles, creating 'quicksand' conditions (Troeh et al. 1991). High water levels in an impoundment can be the result of short or long term runoff situations (Bishop and Bishop 1981). In order to reduce high water levels, the tailings impoundment is normally designed to divert runoff away from it. Subsurface drains may also be installed to facilitate the lowering of the water table. There are several resources in the literature on tailings impoundment stability, both environmental and physical stability (Sharp 1982; Aery and Tiagi 1985; Penman 1990; ICME 1998; Willgoose and Riley 1998; Chappell and Craw 2000). It is generally accepted that plant cover is effective, economically and aesthetically, in the stabilizing tailings dams (Aery and Tiagi 1985). Penman (1998) indicated that failures today are due to inadequate application of known methods, bad designs, poor supervision during construction, or the exclusion of vital components at certain stages of construction.

At the Ray Point tailings facility in Live Oak County, Texas, (uranium tailings) water from the surface of the impoundment was diverted to limit the amount of infiltration into the cover material (1.2 m of clayey sand) (Miller and Davis 1987). The majority of runoff was diverted away from the embankment slopes, via designed swales, to increase the long term stability of the structure. Field measurements indicated that water has migrated a significant distance (~ 150 m) laterally from the impoundment in the last 16 years (Miller and Davis 1987). Minor seepage from the impoundment had occurred, however, the typical tracers associated with uranium tailings seepage have not been detected in wells surrounding the impoundment.

As illustrated by the above cases, water, and especially the control of water, is of great importance in the construction, stability and closure of tailings facilities. In a practical sense, a water balance exists for tailing structures. That is, over a relatively long period of time, the total inflow of water equals the total outflow. Inflow of water to a tailings structure may include: process water (along with tailings), precipitation onto the structure, and surface or underground runoff from adjacent drainage basins (Swaisgood and Toland 1973). Outflow may occur by evaporation, by seepage through embankments and/or underlying materials, or as free water through decant systems, diversion works or spillways (Swaisgood and Toland 1973).

1.2 Objectives

The global objective of this study is to characterize the spatial patterns and variability in soil moisture and salinity on a tailings sand storage facility. This information can then be used to determine whether waterlogging and salinity pose a threat for reclamation of the tailings sand storage facility. Results of this study may be used to help determine reclamation strategies for tailings sand structures, ultimately leading to the successful closure of the structure and attainment of the respective end land use goals.

1.3 Site description

The study site, one cell of a tailings sand storage facility, is located in northern Alberta, Canada, 40 km north of the city of Fort McMurray, in the Athabasca oil sands (Figure 1.1). The tailings sand storage facility is the Southwest Sand Storage Facility (SWSS), located at the Syncrude Canada Ltd. mine, their Mildred Lake operation. The SWSS is located in the southwest corner of Syncrude's mine site, approximately 20 km from the main plant site (Figure 1.2).

1.3.1 Southwest Sand Storage Facility

Syncrude Canada Ltd. is the world's largest producer of crude oil from oil sands and is the largest single source producer in Canada, currently supplying 13 percent of the nation's petroleum requirements (Syncrude Canada Ltd. 2001b). Syncrude began the construction of the Southwest Sand Storage Facility (SWSS) in 1990 to serve as the main site for tailings sand storage; after the original storage site, the Mildred Lake Settling Basin, reached its final design height (Syncrude Canada Ltd. 2001b).

The SWSS is currently the largest operational tailings dam in the world, holding approximately 435 million cubic meters, covering 25 square kilometres (2500 hectares), and standing approximately 40 m high. The structure is in fact an enormous sand pile, set upon a foundation that could comprise limestone, oil sand, Clearwater formation shale, or Pleistocene deposits. It was designed with a 20H:1V downstream slope and a large beach-to-pond ratio. Construction of this structure continues and is scheduled to be complete (reclaimed) by 2015, with certification of the structure by 2023.

Following oil sand mining, the oil (bitumen) is extracted using hot water, steam, and often small amounts of caustic (sodium hydroxide). The extraction water, called 'recycle water' is obtained from the Athabasca River and recycled within the facility; it is generally low in calcium and high in sodium, sulphate and chloride. Once the bitumen is liberated from the sands, the resulting sand-rich 'slurry', referred to as tailings, is settled out.

The slurry, although considerably variable from minute to minute, is typically comprised of 50% solids by weight and contains about 0.7% bitumen (by weight), 80% sand, 16% silt, and 3% clay (with typically 10% fines <44 microns) (McKenna Personal Communication). This slurry is usually further diluted and is piped to deposition areas; e.g., the Southwest Sand Storage Facility. The sand drops out of suspension in the slurry as it is added to the top (the beach) of the structure. Most of the fines and water travel down the graded slopes of the beach forming an area of

standing water, a tailings pond, which changes location frequently, depending on where the slurry is being deposited. The beach area is nearly saturated in most areas.

The tailings sand is added gradationally, with the structure being constructed slowly over time. Some areas are compacted to provide a shell for geotechnical stability. To ensure structure stability, the sides (or embankments) have been constructed with a series of slopes and 'backslopes', or benches, from the toe ditch (bottom) to the beach (top) (Figure 1.3a). Spillways (or lateral berm channels) were constructed to divert surface water off the structure, but currently, the SWSS is not underdrained.

The desired end land use for this structure is a forested ecosystem. The reclamation procedure included, in short, resloping of the land, capping with reclamation material, seeding to barley, then tree planting. Cover crops (quick growing annual species such as barley) are used for temporary cover, mainly to provide protection from erosion (Curtis et al. 1980). Following revegetation, reclamation practices at Syncrude include i) monitoring and maintenance, and ii) certification and custodial transfer (Syncrude Canada Ltd. 2001a).

The SWSS was capped between 1995 and 1998 with a layer of reclamation material (topsoil, 40 – 80 cm in depth). However, reclamation material was added to some of the uppermost areas of the structure, near the beach, in 2002. The topsoil is salvaged material from on-site (mixture of peat and secondary mineral material, clay loam in texture), and is placed directly on the tailings sand. The tailings sand beneath the topsoil falls between a sand and sandy loam texture. Moskal (1999) reported that the tailings sand is closest to a loamy sand in terms of moisture retention, and in general has a low moisture holding capacity.

Species planted included trembling aspen (*Populus tremuloides*), Siberian larch (*Larix siberica*), hybrid poplar (*Populus* sp. hybrid), white spruce (*Picea glauca*), jackpine (*Pinus banksiana*), dogwood (*Cornus stolonifera*), and a few black spruce (*Picea mariana*) (McKenna Personal Communication). Not all areas of the SWSS are

vegetated however, as Syncrude has suspended revegetation of the structure after indications of salinity, sodicity and high water tables. Preliminary measurements showed an increasing trend in electrical conductivity (EC) over 1997 – 2000 and a computer analysis of seepage showed indications of high water tables at essentially steady state levels (McKenna and Qualizza Personal Communication). This preliminary information raised concerns as to whether or not vegetation would establish and survive on the SWSS.

1.3.2 Instrumented Watershed

The study site encompasses an area on one of the SWSS side slopes (cell 32); on the east-facing section, running from the base of the facility to its current crest. The site is termed the 'instrumented watershed', being that this particular cell on the structure was delineated for the installation of instrumentation to examine hydrologic and chemical properties of the SWSS. The study site is approximately 0.26 km^2 (26 ha) in area. It is anticipated that this instrumented watershed will serve as a representative 'slice' of the entire SWSS 'pie', and provide an indication of how the tailings structure behaves as a whole. The approximate location of the instrumented watershed, in relation to the entire Syncrude site, is illustrated by the star in Figure 1.2. To the West of the instrumented watershed is the beach (exposed sand on top of the SWSS), and there is a road to the east of the toe ditch which separates the SWSS from a forested area. On this site, the tailings sand was overlain with topsoil (direct placement), the target depth of topsoil being 60 – 80 cm.

Preliminary results of a vegetation survey conducted on the instrumented watershed in July 2002 indicated that there is very low biodiversity with a domination of weedy species. Dominant species providing ground cover include horsetail (*Equisetum arvense*) and fireweed (*Epilobium angustifolia*) (two most dominant native species), sow thistle (*Sonchus arvense*), and white and yellow sweet clover (*Melilotus alba*, *Melilotus officinalis*) (Wilkinson Personal Communication). Tree and shrub species (most of which Syncrude introduced) include Siberian larch (*Larix siberica*), hybrid poplar (*Populus* sp. hybrid), trembling aspen (*Populus tremuloides*), white spruce

(*Picea glauca*), four species of willow (*Salix* sp.), buffaloberry (*Shepherdia canadensis*), and red osier dogwood (*Cornus stolonifera*), (Wilkinson Personal Communication). Vegetation, both species composition and density, is quite spatially variable on the site.

The site includes 5 slopes (sloped and backsloped), extending from the base of the structure upward. For the purpose of this study the 5 slopes were named A, B, C, D, and E as shown in Figure 1.3. The cross section of the instrumented watershed is as shown in Figure 1.3a, however, the uppermost slope and backslope (those above slope 'E') were not present when the study began in 2001, and slope E was only reclaimed half way up the slope. Therefore, this study only examines the five slopes depicted in Figure 1.3b, and does not include the newly constructed slopes which reach up towards the beach. The first forward slope of the site is approximately 90 m in length, at a 10% angle. Following this is a backslope or bench (2% slope) approximately 80 m in length, which slopes downward into a spillway or wetlands area. This pattern then repeats, leading up to the beach, with the forward slope being 80 – 95 m in length and the backslopes being 80 – 85 m in length. The total elevation of the site (from the toe to the top of slope E) is approximately 30 m. The site is divided into four plots (numbered 1 to 4), running from slope A to slope E (Figure 1.3b). These rectangular plots are each 100 m wide by 650 m long and act as four replicates.

Each replicate plot can be further divided into two zones, based on slope position, as depicted by the shaded lines in Figure 1.3a. These zones are defined only by slope position (sloped or backsloped), and not by other characteristics. For the most part, however, each of the five slopes will be treated individually, and regarded as slopes A, B, C, D, and E as depicted in Figure 1.3b. There are constructed waterways (lateral berm channels; referred to here as wetlands areas) between slopes B and C and between slope D and E, which are designed to divert runoff and seepage water off the structure (laterally across the site). To the left of plot 1 is a grassy swale that

collects the diverted surface and/or seepage water, allowing the water to collect at the toe ditch where it can be removed from the structure.

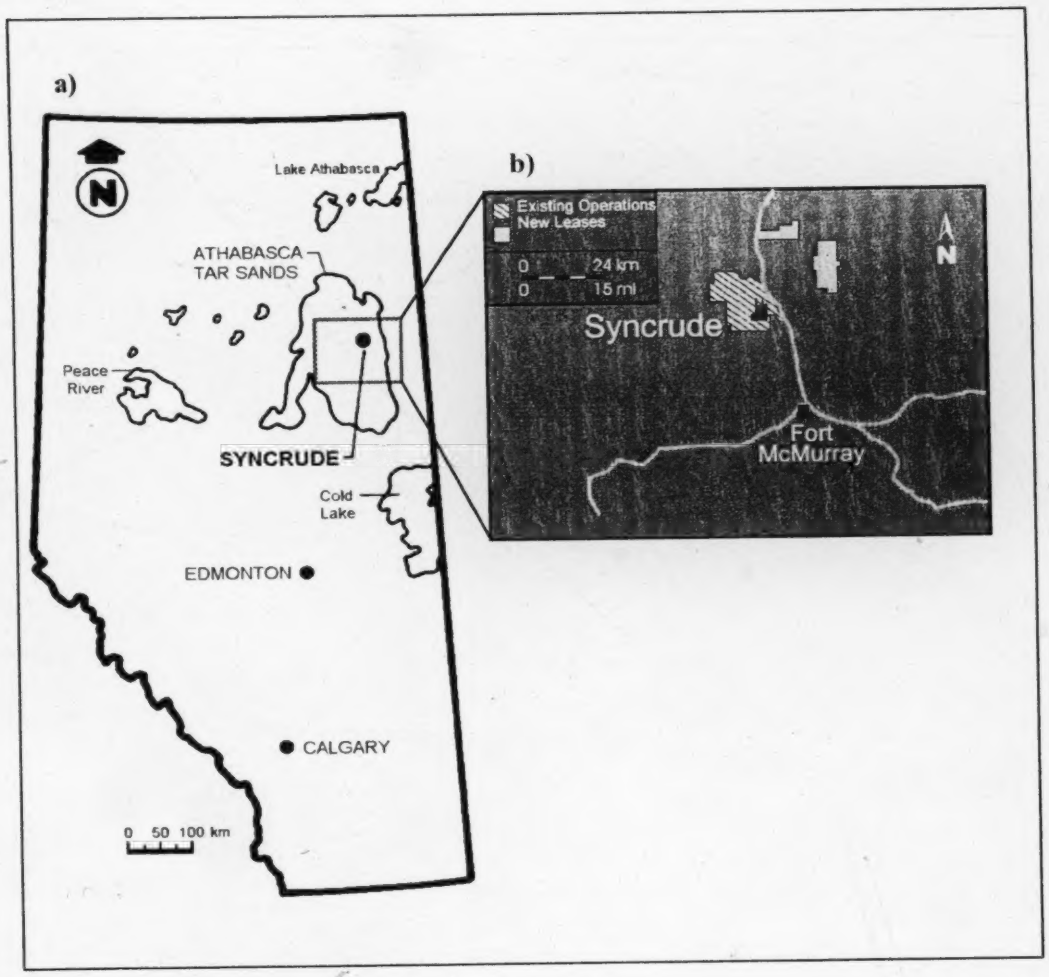

Figure 1.1 Site Location
a) map of Alberta, adapted from Nyren and Mittal (1978) b) Fort McMurray/Syncrude area, adapted from Conoco Inc. (2002)

Figure 1.2 Location of SWSS instrumented watershed
Solid square represents main plant site (Syncrude's Mildred Lake operation), dotted line encloses the SWSS structure, and star represents cell 32 (the instrumented watershed).
(Obtained from Syncrude Canada Ltd.)

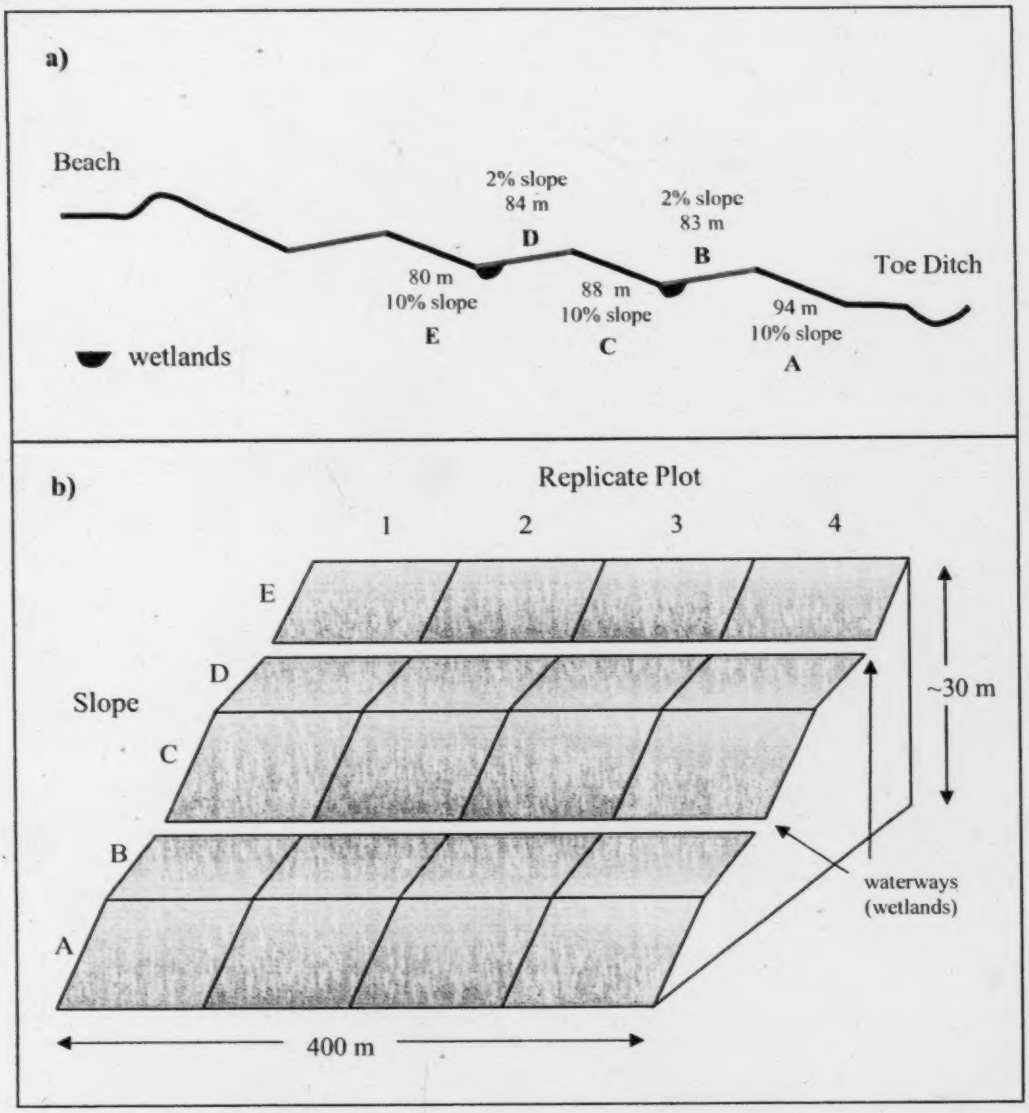

Figure 1.3 a) Vertical cross-section schematic of instrumented watershed b) Schematic of study site, on instrumented watershed

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2.0 SOIL MOISTURE REGIME OF A SAND STORAGE FACILITY

2.1 Introduction

Hydrologic regime is defined by Curtis et al. (1980) as the entire state of water movement in a given area. In natural settings, soil moisture regimes are monitored for a number of reasons: to assess vegetative stability/stress, to determine the position of the water table, to obtain a moisture profile of the soil, or for use in a water balance (to name but a few). Soil moisture fits into the hydrologic equation as follows:

$$P = ET + D + R \pm \Delta S_m$$

where P is precipitation, ET is evapotranspiration, D is deep drainage (percolation), R is runoff, and ΔS_m is the change in soil moisture. If D and R are assumed to be = 0 (or are known), then ΔS_m can be used to determine ET.

The soil is of primary importance in the regulation of the hydrologic regime. Soil characteristics (structure, texture, bulk density, etc.) determine the amount of precipitation that infiltrates, the amount of water leaving via evaporation and plant uptake, and ultimately the rate at which water is transmitted below the ground surface. The amount of water held in the soil is often expressed as the volume of water in proportion to the total soil volume (Arnell 2002):

$$\theta = \frac{V_w}{V_t} \quad \left[cm^3\ cm^{-3}\right]$$

where θ is volumetric soil moisture (often reported as a percent), V_w is the volume of water and V_t is the total volume of the soil. The amount of moisture that can be held in the soil is largely dependent on soil texture; finer textured soil has smaller pores, which hold water more tightly. Soil texture/structure also dictates the ability for water to flow; with coarser textured soil (larger pores) generally providing greater ease of flow than soil with smaller pores. The degree of saturation, however, also

plays a role in how easily water can flow through the soil medium, with greater flow under saturated conditions, due to higher hydraulic conductivities (Chanasyk 1980).

Many soil moisture measurement techniques are available, each with its own advantages and disadvantages. The gravimetric method involves taking soil samples and comparing the weight before and after drying; a method which is accurate (Arnell 2002) but destructive and not reproducible at set locations. Radiological methods indirectly measure soil moisture by emitting neutrons (neutron probe method) or gamma rays, and evaluating how these particles interact with the soil; methods which are non-destructive and provide reproducibility, but require calibration. Measurement methods that utilize the dielectric properties of soil and water have become popular as another indirect way of measuring soil moisture, and involve sending an electromagnetic pulse through the soil (capacitance probes, time-domain reflectometry probes). These methods can be used to measure soil moisture over time and are non-destructive, but they also require calibration and can be influenced by saline soil conditions (Wyseure et al. 1997; Sun et al. 2000). Recently, remote sensing and ground-penetrating radar have been used to passively measure soil moisture, which can be helpful in determining the spatial pattern of soil moisture, but can generally only measure near surface moisture content (Arnell 2002). Tensiometers are another device used to measure soil moisture, by quantifying soil matric potential or suction, and can provide continuous measurements, but are not accurate at low moisture contents (high suctions).

2.2 Objectives

In this study, soil moisture was monitored to assess the status of reclamation on a tailings sand storage facility and the feasibility for revegetation of this site, as well as to help understand soil salinity. On tailings sand structures, the formation of a water table, and/or waterlogging, is often an issue, being that these facilities are constructed with a tailings slurry, which is primarily liquid (Barth 1986, WMC Resources Ltd.).

The global objective of this component of the study was to quantify the soil moisture regime within the SWSS Facility and its variability in time and space. Research questions of specific interest are:

i. Are the soils saturated or unsaturated? At/to what depth?
ii. Does soil moisture vary by zone/slope type (backslope, forward slope)?

2.3 Materials and Methods

Soil moisture was monitored in each of four replicate plots (Figure 2.1). Neutron probes were used to investigate soil moisture with depth, while bulk density with depth was measured using moisture/density gauges.

A meteorological station was installed upper mid-site (Figure 2.1a) in summer 2001 to measure air temperature, solar radiation, precipitation, relative humidity, wind speed and wind direction on an hourly basis. Collection of these data on the instrumented watershed began in July 2001.

2.3.1 Neutron Probes

Neutron probes measure neutron scattering, an indirect means of determining soil moisture content (Schmugge et al. 1980). Taking into account the size of the study area and the number of measurements required, the neutron probe method of soil moisture measurement was most suitable. Neutron probes have the advantage of high precision and straight forward operation, plus measurements can be repeated at the same location, multiple times (Topp 1988). Neutron probes also meet the requirement of being able to measure moisture variations over a large study area, and for relatively large volumes, while remaining non-destructive (Chanasyk and Naeth 1996). However, neutron probes have the disadvantage of poor measurement resolution near the ground surface and near textural discontinuities.

The neutron access tubes used were thin-wall aluminum irrigation tubing, open at both ends, with a diameter of 5 cm. These 2 m-long tubes were installed by hand-

augering a hole, then advancing the tube into it using a twisting/shimmying action. The diameter of the augered hole was the same size as the tube (5 cm), to ensure a tight fit. This is important, given that any air space in the vicinity of the access tube will influence the thermalized neutron distribution and consequently the neutron count obtained by the neutron probe (Gardner 1986). The probe also fits snugly inside the access tubes, minimizing air gaps. The access tubes were installed to extend out of the ground, generally 10 – 15 cm above the soil surface.

Instrumentation was set out along a single transect in each of the four replicate plots, i.e., four transects. Along each transect were 13 neutron access tubes, numbered from 1 at the toe to 13 at the top of the site (Figure 2.1). Three tubes were installed on each of the slopes (A – D, inclusive), with only one tube on the uppermost slope (E). In total, there are 52 neutron access tubes on the instrumented watershed. The neutron access tubes along any one transect were 15 – 20 m apart on the sloped areas, and approximately 12 m apart on the backslopes.

Two neutron probes (Campbell Pacific Nuclear Model 503DR) were used in this study. Soil moisture measurements were made by lowering the neutron probe down each access tube. Measurements were taken in 10-cm intervals, starting at 15 cm below the surface and reaching down as far as possible in the neutron access tubes. Different maximum depths were reached, depending upon access tube installation, as not all tubes could be installed to 2 m (due to soil slumping at depth during installation). The overall maximum depth of measurement via neutron probe was 175 cm below the surface, with the maximum depth collectively reached by all tubes being 120 cm.

The two neutron probes were cross-referenced against one 'master' neutron probe, which had been calibrated locally for oil sands soils. Calibration equations were then formulated for the two probes based on the cross reference. Standard counts were taken at the start and end of each day, with the probe in its shield while sitting on top of the neutron probe case. Normally, one set of soil moisture readings at the site

would take approximately 6 hours using two probes. On a given date, each probe was used to measure soil moisture in two replicate plots (one probe measuring replicates 1 and 2, the other measuring replicates 3 and 4). The same neutron probe was generally used to read the same tubes on all measurement dates.

Over the course of the 2-year study, 15 sets of neutron probe data were collected, taken roughly on a bi-weekly basis over the summers of 2001 and 2002, with 7 data sets collected in 2001 and 8 collected in 2002. Field measurements in 2001 started in early June (start of study), whereas 2002 field measurements started in late May (late start due to ice in access tubes). Measurements ceased in mid-September each year.

Bulk density was measured in each of the neutron access tubes on August 27, 2002, using a Campbell Pacific Nuclear Model 501 depth moisture/density gauge, to determine the degree of saturation in the different soil materials (tailings sand and clay loam topsoil). It is assumed that bulk density does not change over the study period (from 2001 – 2002). The moisture channel of the moisture/density probe was calibrated against that of the master neutron probe, while the density calibration equation as supplied by the manufacturer was accepted. Porosity was determined from the bulk density data using the following equation:

$$n = (1 - D_b/2.65)$$

where n is porosity (as a decimal) and D_b is the soil bulk density (Mg m^{-3}). Particle density is assumed to be 2.65 Mg m^{-3}, since the topsoil material is largely mineral, with minimal organic matter. Percent saturation was determined from volumetric moisture content (VMC) at a specific depth, using the bulk density measured at that depth, according to the following equation:

$$\% \text{ saturation} = \frac{VMC \times 100\%}{1-(D_b/2.65)} = \frac{VMC}{n} \text{ x } 100\%$$

Three Total Soil Water (TSW) parameters were chosen to quantify the soil moisture regime: TSW40, TSW120 and TSW80-120. TSW40, for example, is the amount of

water, in mm, found in the soil profile to a depth of 40 cm. This is calculated from volumetric moisture content (expressed as percent) in the following manner:

$$\text{TSW40} = \left(\frac{VMC_{15}}{100} \times 200 \right) + VMC_{25} + VMC_{35}$$

where VMC_{15} is the volumetric moisture content at a depth of 15 cm (assumed to represent the top 20 cm of soil), and VMC_{25} and VMC_{35} are the volumetric moisture contents at depths of 25 cm and 35 cm (respectively), all expressed as a percent. TSW120 and TSW80-120 were calculated as per the above equation, except considering the appropriate depth increments. The three TSW parameters represent different sections of the profile; TSW40 represents the topsoil, TSW120 represents the entire profile, and TSW80-120 covers part of the tailings sand portion of the profile. The 120-cm depth represents the greatest depth to which most access tubes could be read.

2.3.2 Statistical Analysis

The statistical analysis was somewhat challenging, being that the site setup was not a conventional one, with applied treatments and randomization. The main purpose of the statistical analysis was to evaluate the variation among the four replicates, variation among the five different slopes, variation among tubes of a slope, and variation on either side of a crest or waterway. For the most part, statistics were employed (using SAS statistical software) to confirm trends that were recognized in the data by prior visual and graphical analysis.

A split-split plot (in time) analysis was initially used, with replicate, slope, tube and date as the sources of variation, but this proved difficult being that slope E has only 1 tube and it was not possible to keep the tubes numbered from 1 – 13 (so that they could be individually compared). A repeated measures analysis was performed to test for sphericity and autocorrelation between dates. Autocorrelation was found in the data, which is not surprising for soil moisture data, meaning that assumptions made in the split plot analysis (equal variances and independent variables) were no longer valid. The choices for analysis were then to either move to a more complicated

multivariate analysis, or to stick with the univariate analysis and remove date, as a source of variation, from the model.

It was decided that, since it is not useful to statistically compare soil moisture on different dates (with so many factors contributing to the change in soil moisture from date to date), a univariate approach would best meet the purpose outlined above. A Complete Block design was used for analysis, with replicate and tube being the sources of variation, according to the following statistical model:

$$Y_{ij} = \mu + \alpha_i + \tau_j + \varepsilon_{ij}$$

where Y_{ij} = observed soil moisture

μ = overall mean

α_i = effects of replicate plot (1, 2, 3, 4)

τ_j = effects tube (1, 2, 3, ..., 13)

e_{ij} = experimental error (replicate*tube interaction)

The neutron probe data were tested according to this model, for each date individually (15 dates over the 2 field seasons). Contrasts were set up to test for variation among slopes and between different tubes. In all statistical analyses, a confidence level of 95% was chosen ($\alpha = 0.05$) to distinguish statistically significant variation.

2.4 Results and Discussion

2.4.1 Meteorological Trends

The full meteorological data set from the SWSS instrumented watershed is given in the Appendix (Tables 6.1 and 6.2), along with figures of temperature, radiation, precipitation and potential evapotranspiration (Figures 6.1 and 6.2). Potential evapotranspiration (calculated using the Penman-Monteith method) was not used in this study, but included as additional data. Meteorological data from the Fort McMurray Airport (located just south of Fort McMurray) were obtained from

Environment Canada (2003), and data from a bison pasture, located approximately 10 km northeast of the study site, was also utilized. The long term normal (LTN) data from the Fort McMurray airport (average monthly precipitation and temperature over 1971 – 2000) was used to compare temperature and precipitation on the SWSS over the study period (Table 2.1). Only the months of April – September were used to compare SWSS climate data to the LTN for the region, being that field work was completed over this time frame in 2001 and 2002. Since meteorological data collection on the SWSS instrumented watershed began in July 2001, data from the Syncrude Bison Pasture are included in Table 2.1 to represent the instrumented watershed for April – June of 2001.

Overall, the 2001 field season was slightly drier and warmer than 2002. The months of April, May and August, however, were wetter in 2001 than in 2002. Most of the precipitation in this region falls in July (56.1 mm in 2001, 100.3 mm in 2002). The maximum temperature at the SWSS, over the two field seasons, was 35 °C on June 27, 2002. Average monthly temperatures for the instrumented watershed were comparable to the LTNs for the Fort McMurray region.

The 2001 field season was drier than the LTN for the region in every month (over April – September) except May. Similarly, 2002 was drier than the LTN in every month (over April – September) except July, with September being comparable. In spite of the considerable amount of precipitation that fell on the SWSS in July 2002, conditions on site (and in the province of Alberta) were relatively dry in 2001 and 2002 (as a result of low precipitation in both the summer and winter). The years leading up to this study (namely 1999 and 2000) were considerable dry years in relation to the LTN for the area.

2.4.2 Soil Moisture Trends

The wettest areas on site were at tubes 6 and 13 (Tables 2.2, 2.3 and 2.4), especially for TSW120. The TSW values in Tables 2.2, 2.3 and 2.4 were averaged over the four

replicates. There was more variation in soil moisture among tubes for TSW120 than for TSW40. The coefficient of variation (from the statistical analysis, Tables 6.3 – 6.5 in the Appendix) increases from TSW40 (lowest CV) to TSW120 (highest CV, most variable), with the coefficient of variation for TSW80-120 being intermediate. For 6 of the 15 dates analyzed for TSW40, the statistical model was not significant, suggesting that there was not significant variation in soil moisture between the four replicates or 13 tubes at a depth of 40 cm. TSW40 was quite similar at all tube locations and ranged from 55 – 134 mm; TSW120, on the other hand, ranged from 92 – 490 mm. The statistical model for TSW120 was significant for all 15 dates and significant variation was found between the different tube locations. The driest tube location was tube 11. For TSW120, the list of tube locations in ascending order of wetness is:

11, 10, (7, 8, 9), 12, 3, (4, 2), 1, 5, (6, 13)

where tubes in brackets refer to tubes with similar wetness. The spatial variation in soil moisture is displayed in Figure 2.2, a plan view contour plot of TSW120. Standing water was found in tubes 13 regularly, and occasionally in tubes 6 and 5 and tube 1 (in replicate 4 only).

TSW80-120 ranged from 4 mm (at tube location 11) to 189 mm (at tube location 6) and had a similar pattern for wetness, among tube locations, as shown above for TSW120. The statistical model for TSW80-120 was significant for all dates investigated, with significant variation found among the different tube locations. In comparing TSW40 and TSW 80-120 (Tables 2.2 and 2.4) it is evident that the values were similar at some tube locations (1, 2, 4), with most of the locations being wetter in the top 40 cm (tube locations 3, 7 – 12), and the remainder of the locations being wetter in the 80 – 120 cm depth increment (tube locations 5, 6 and 13).

The driest area was around tubes 7 to 12, with tube location 11 being the driest. This dry area was largest in replicate 1 and steadily decreased in size moving to Replicate 4 (Figure 2.2). Tube location 11 is of interest, being that it is the center tube on slope D and was very dry, whereas the tube locations on either side of it were not so dry,

especially in the case of tube location 12 (Tables 2.2 to 2.3, and Figure 2.3). From observation, the vegetation in this area was less dense than in areas further downslope of the site. Statistically, tube locations 10, 11 and 12 were not significantly different from each other with respect to soil moisture (TSW40, TSW120 or TSW80-120). On slopes C and D (tubes 7 – 12) there appears to be no influence from shallow groundwater, but rather the near surface zone (topsoil) dominates the moisture regime.

Each of the slopes (A to E from Figure 2.1) had a distinct soil moisture trend or pattern associated with it (Figure 2.3). Moving upslope from the toe on slope A, there was a decrease in soil moisture (from tube 1 to tube 3). On slope B (the first backslope), soil moisture increased towards the first waterway (from tube 4 to 6). From that waterway upslope, on slope C (tubes 7 to 9), there was only a slight increasing trend in soil moisture, with soil moisture being generally low in this area. On slope D (tubes 10 to 12), soil moisture was at its lowest level on site, and there was no trend moving upslope. The top slope, E, holds tube 13, which was a wet tube location, similar in wetness to tube 6.

Slopes A and C are both forward slopes, but they had statistically different moisture regimes. Soil moisture decreased moving upslope on A, but increased moving upslope on C. The magnitude of soil moisture was also different on these two slopes, with slope A generally being much wetter than slope C. In the same respect, backslopes B and D were statistically different, and in fact were opposites in terms of soil moisture status; slope B was the wettest area on site, while slope D was the driest. One possible explanation for this difference may be the size of the two wetland areas adjacent to the two backslopes. The wetland on backslope B is larger, deeper and more persistent than that on backslope D. Slope E was statistically different from the two other forward slopes (slopes A and C), but also was the most recently reclaimed slope on site, and had much less vegetation than the areas downslope.

Trends in soil moisture on either side of a crest or a waterway are of interest. Tubes 3 and 4, which border the first crest, were not statistically different, with tube 3 being just slightly drier than tube 4 (Figure 2.3). Similarly, tubes 9 and 10, which border the second crest, were not significantly different, with tube 10 being just slightly drier than tube 9. However, the tubes that border either side of the waterways (tubes 6 and 7 and tubes 12 and 13) were statistically different. At the first waterway, the tube 6 location was much wetter than tube location 7 (which is upslope from the waterway). At the second waterway, the tube 13 location (on the upslope) was much wetter than tube 12, which is on the bench. The soil moisture regime at tube location 6 appears to be affected by the adjacent wetland area, whereas tube location 12 does not. This could be due to varying distance of these tubes to the waterways (especially being that the waterway near tube 6 is larger). The soil moisture regime at tube location 13 was most likely affected by saturated conditions on the beach (top of the structure). Other tube locations which were found to be statistically different were 1 and 3 (slope A) and 4 and 6 (slope B); with tube locations 1 and 6 (low-slope positions) being wetter, and with locations 3 and 4 (found at the crest) being drier.

The lowest slope position of the site (tube location 1) was drier than originally expected. This may be due to the greater vegetation cover in this area, and hence, likely greater moisture loss due to evapotranspiration. Soil moisture levels at these tubes fell somewhere in the mid moisture range for the site, with a volumetric moisture content of about 15 – 20 % near the surface, 25 – 30 % at the topsoil-tailings sand interface, and about 20 – 25 % at depth (145 cm). Tubes 1 in replicates 1 and 4 (i.e., tubes 1-1 and especially 4-1), however, were wetter than the tubes in the same position in the other two replicates.

2.4.3 Soil Moisture Variability

The spatial variability in soil moisture was rather complex on the slopes of the instrumented watershed. Volumetric soil moisture (Figure 2.4) ranged from 0 – 45 %. This immense variation occurs in the tailings sand and at depth, while moisture at the surface (15 – 35 cm depth) is relatively uniform across the site (ranging from 20 –

35 % moisture by volume). Note that in Figure 2.4a, the different neutron access tube locations are not meant to be distinguished, but rather the purpose of this graph is simply to show the immense range in soil moisture values across the site.

The 13 tube locations can be grouped into two major moisture groups: moderate to wet (tubes 1, 2, 4 – 6 and 13) and dry (tubes 3 and 7 – 12) (Figure 2.4 b and c). In examining the profiles of soil moisture with depth, the tubes can also be conceptualized into three moisture profiles (I, II, and III in Figure 2.5): i) drier areas where soil moisture peaks in the topsoil at a depth of about 30 cm, then continues to gradual decrease and stays fairly dry in the tailings sand (tubes 7, 8, 9 and 11); ii) areas with moderate moisture, where the moisture content in the topsoil is greater than in the first case, again peaking at about 30 cm, then decreases into the tailings sand, but increases again with depth in the tailings sand (tubes 1, 2, 3, 4, 10 and 12); and iii) wetter areas, where the moisture content in the topsoil is a bit higher than in the second case, then continually increases with depth in the tailings sand (tubes 5, 6 and 13). Moisture profiles I and II are actually similar in trend or pattern to a depth of approximately 95 cm, and start to differ thereafter.

For most tubes, soil moisture peaked in the topsoil at a depth of approximately 25 – 30 cm. In Figure 2.4 (b and c), a prominent trough in VMC was evident for most tube locations, however, this trough appears at different depths. For tube locations 10, 11 and 12, the trough occurred at a depth of approximately 55 cm. For tube locations 1, 3 and 7, however, the trough appeared at a depth of 95 or 105 cm. This may be explained by variations in the depth of topsoil on site, as the trough in soil moisture is located beneath the interface between topsoil and tailings sand. Figure 2.6 is a contour plot of topsoil depth over the site (or the depth to the topsoil-tailings sand interface). The average interface depth (across all replicates) is given in Table 6.6 (Appendix). The tube locations that have a VMC trough around 55 cm (tubes 10, 11 and 12) have a shallower depth of topsoil, while those tubes with a VMC trough around 100 cm (tubes 1, 3 and 7) have a greater topsoil depth. It is evident that the topsoil is successfully holding moisture, and the depth of topsoil likely has a direct

effect on the soil moisture profile (i.e., how much moisture can be stored above the tailings sand).

The statistical results for interface depth are given in the Appendix (Table 6.6). Replicate 1 has a statistically smaller depth of topsoil than the other three replicates, while topsoil depths at replicates 2, 3, and 4 are not significantly different. The only statistically significant difference in topsoil depth among the 13 tube locations (averaged across the four replicates) was for tube locations 5 and 10 (with tube location 5 having the greatest depth of topsoil and tube location 10 having the least).

A regression analysis between topsoil depth and TSW (40 and 120 cm) revealed no direct relationship between overall soil moisture status and topsoil depth; trends in soil moisture did not necessarily coincide with patterns in topsoil depth. This is likely because many factors, besides topsoil depth, can contribute to the variation in soil moisture: spatial variation in peat content of the topsoil, vegetation, topsoil composition, and meteorological variation. It may also be that, because this site has been relatively dry, vegetation has been taking up most of the available moisture, so that conditions have not been wet enough to be able to test for effects of topsoil depth on soil moisture.

Variation in soil moisture at a given depth, over a single field season, and from 2001 to 2002, was minimal (Figure 2.7). Figure 2.7 shows the change in soil moisture over time, at depths of 40 and 120 cm, for three tube locations: tube 6 (the wettest), tube 3 (moderate moisture), and tube 11 (driest). Over the 2001 field season, most of the tubes showed a slight decrease in soil moisture, which follows the decrease in monthly rainfall over the season (Table 2.1). In 2002, however, soil moisture remained rather constant, with a slight increase at the end of the season (September). Overall, the two years had similar soil moisture regimes, despite any meteorological differences. The lack of variation in soil moisture from year to year may be due to vegetation taking up moisture as it becomes available (being that conditions have been dry in this area), causing soil moisture to appear constant over time.

An increase in soil moisture was evident over the winter period, between the two field seasons, for all of the tube locations (Table 2.2, compare Sept. 21, 2001 with May 24, 2002). At tube 9, for example, the total soil moisture at a depth of 40 cm increased from 69 mm in fall 2001 to 118 mm in spring 2002 (a 49 mm increase). Similar increases in soil moisture, attributable to snowmelt infiltration, were evident at tubes 2 and 4. In the entire profile (to a depth of 120 cm), the increase in soil moisture between field seasons was even more apparent (Table 2.3), with tube location 4 having the greatest increase (91 mm). Tube 11 was the only tube location where total soil moisture to a depth of 120 cm did not increase from fall 2001 to spring 2002. Very little change in soil moisture was observed in the tailings sand (depth increment of 80 – 120 cm) between field seasons (Table 2.4). The greatest increase in soil moisture, in the tailings sand (TSW80-120) from fall 2001 to spring 2002 was 26 mm at tube location 12.

Tube location 13 continually received water over the study period, as water needed to be bailed out of the access tubes every two weeks. The wet conditions around tubes 13 can likely be attributed to the apparent artesian flow occurring in this area from the beach area (McKenna Personal Communication). Tube location 6 occasionally required bailing as well, as did tube 4-1 (but not the other three tube 1 locations). The wet conditions around tube location 6 (Figure 2.2) may be a result of local flow systems operating in the vicinity of the wetlands areas. These conditions are not apparent in and around tube location 12, which is situated on a bench next to a waterway, just as tube location 6 is. The same is true for tube locations 13 and 7, on the upslope side of a waterway; they have very dissimilar soil moisture characteristics, suggesting that the flow regimes in these areas are different.

2.4.4 Replication

The results of the statistical analysis for soil moisture are given in the Appendix, Tables 6.3 – 6.5. The statistical analysis revealed that, for the majority of the dates investigated (12 of 15), the four replicates were not a statistically significant source of

variation in soil moisture (TSW120); as was the case for TSW40, for all 15 dates. Being that soil moisture is similar for the four replicates, it is reasonable to average moisture values at one tube for all four replicates. The only instance where the four replicates were a significant source of variation was in the case of TSW80-120; replicate 2 is significantly drier at a depth of 180-120 cm than the other replicates.

If there was a desire to reduce monitoring in the future, a single tube could be chosen from each of the three moisture profile types given in Figure 2.5, or tubes could be chosen to represent each slope, such as tubes 1, 3, 6, 8, 11 and 13, which would also represent each moisture group. Since the four plots are good replicates, monitoring could also be reduced to three plots instead of four.

2.4.5 Percent Saturation

Bulk density on site ranged between 0.80 – 1.60 Mg m^{-3} in the topsoil and between 1.00 – 1.40 Mg m^{-3} in the tailings sand (Table 2.5). Using the average bulk density for topsoil and tailings sand, porosity can be calculated and an average value for saturation (in percent by volume) can be obtained for each of the materials. The average bulk density in the topsoil (0 – 60 cm) was 1.38 Mg m^{-3}, which means that saturation in the topsoil is reached at a volumetric moisture content of approximately 48 %. The average bulk density in the tailings sand (60+ cm) was 1.18 Mg m^{-3}, translating to approximately 55 % porosity, or saturation at 55 % moisture by volume. Areas which were relatively dense were tube location 1 to a depth of 65 cm, tube location 5 to a depth of 55 cm, and tube location 7 to a depth of 45 cm.

Tables 2.6 and 2.7 give percent saturation with depth (averaged across all four replicates) for 2 dates: June 9, 2001 (a relatively wet day) and September 21, 2001 (a relatively dry day). Percent saturation appears fairly constant between the two dates examined, especially in the case of tube 13, which showed very little change in percent saturation over the two dates shown, and stayed consistently wet.

The only locations for which soil moisture approached saturation were tube locations 6 and 13, in the tailings sand. Saturation is nowhere reached in the topsoil. The highest percent saturation value in the topsoil (depth of 15 – 35 cm) was found at tube location 12 (81 % saturation) on June 9, 2001 and tube 6 (63 % saturation) on September 21, 2001 (Tables 2.6 and 2.7). Although tube 11 had the lowest moisture in the tailings sand (close to 0% saturation), soil moisture at its surface was comparable to other tube locations; the lowest percent saturation in the topsoil was found at tube locations 3, 9 and 10. Percent saturation in the upper topsoil (15 – 35 cm depth) ranged from 25 – 70 %, while percent saturation in the tailings sand is highly variable, ranging from 0 – 90 %. Despite tubes 5, 6 and 13, percent saturation is quite low in the tailings sand. Figure 6.3 (in the Appendix) shows percent saturation with depth, in comparison to other soil parameters.

Figure 2.8 gives histograms of percent saturation at depths of 40 cm (topsoil) and 120 cm (tailings sand), for each of the 13 tube locations (averaged across the four replicates). In the topsoil, percent saturation ranged from 31 – 80 %, with more values closer to the high end (61 – 70 %) on the wet day and more values closer to low end (31 – 50 %) on the dry day. In the tailings sand (depth of 120 cm), percent saturation values of 0 – 10 % were most common on both the wet and dry days, and there was essentially no difference in percent saturation values between the wet and dry day.

Tube locations 6 and 13 and tube 4-1 required bailing, as water collected in these access tubes. This would mean that the water table is found in the range of measurement at these access tubes, however there were no 100 % saturation values recorded. This may be a result of entrapped air, the approximate equation used to calculate porosity, or a result of the assumption of particle density (2.65 Mg m^{-3}) being an overestimation.

With some areas of tailings sand having such low moisture, the question arises as to whether or not the tailings sand can be wetted. Following pressure plate analysis of

soil samples from the instrumented watershed, it was concluded that, once dry, the tailings sand cannot be easily wetted. If the tailings sand is in fact hydrophobic, this will have an important bearing on the water regime of the SWSS and possibly on the viability of vegetation on site (especially deeper rooted tree species).

2.5 Conclusions

On the SWSS instrumented watershed, the near surface dominates the moisture regime, with little or no apparent influence of shallow groundwater. The root zone is not affected by high water tables or waterlogging, as saturated was not found in the topsoil. The only areas on site where saturation is reached near the topsoil-tailings sand interface are on the first backslope (tube 6), and on the upper slope (tube 13). These areas are the wettest on site, and both are adjacent to waterways (wetland areas). The wetter conditions found in each of these areas are likely the result of two different mechanisms. Tube location 6 could be receiving water from the adjacent waterway, and/or from further up slope as part of a larger flow system. Tube location 13 is continually receiving water over time, likely from the top of the structure, where the tailings slurry is applied. The reclamation material appears to be holding moisture adequately, however, most of the tailings sand below is quite dry. There is the risk in some areas on site (second forward slope and backslope), where moisture in the tailings sand is very low, that the sand in these areas is hydrophobic.

Similar slopes were not replicates; in fact, the two backslopes had opposite soil moisture trends. This could be a result of the different ages since construction (area near the toe is older in age compared to the areas at higher elevation on the site) or the difference in vegetation near the toe versus near slope E. Of course, soil moisture differences are also a result of the difference in topographical position and the effect of the hydrologic regime, which is likely driven by the addition of tailings slurry to the top of the tailings sand structure, and the dynamics surrounding the two waterways or wetland areas.

Table 2.1 a) Monthly precipitation (mm) b) Average monthly temperature (°C)

a)

Month	SWSS		Bison Pasture			Airport
	2001	2002	2001	2002	10-yr Ave*	LTN°
Apr	n/a	0	15.0	4.0	8.8	21.7
May	n/a	9.9	48.0	13.0	27.4	36.9
Jun	n/a	49.0	34.0	48.0	55.8	74.8
Jul	56.1	100.3	55.0	105.0	57.1	81.3
Aug	48.5	33.8	46.0	38.0	43.7	72.7
Sep	13.7	47.2	3.0	20.0^	25.0	46.8
Total	n/a	240.3	201.0	208.0	217.8	334.2

* 10- or 11-year average (1992 - 2000 or 1993 - 2002)

° Environment Canada LTN (from Fort McMurray Airport (1971 - 2000))

^ Includes data for Sept 1 to 11

b)

Month	SWSS		Bison Pasture			Airport
	2001	2002	2001	2002	10-yr Ave*	LTN°
Apr	n/a	-2.1	4.0	-2.8	2.7	3.4
May	n/a	7.5	11.0	7.2	10.1	10.4
Jun	n/a	17.1	15.0	17.2	15.3	14.7
Jul	18.1	17.3	18.0	17.4	17.6	16.8
Aug	17.1	15.1	17.0	15.0	16.1	15.3
Sep	11.7	9.4	12.0	12.1^	10.8	9.4
Average	n/a	11.4	12.8	11.7	12.1	11.7

* 10- or 11-year average (1992 - 2000 or 1993 - 2002)

° Environment Canada LTN (from Fort McMurray Airport (1971 - 2000))

^ Includes data for Sept 1 to 11

Table 2.2 TSW40 (mm) for each access tube location
Averaged across all four replicates.

Date	Ppt.* (mm)	Tubes 1	2	3	4	5	6	7	8	9	10	11	12	13
June 9, 01	n/a	107	114	91	117	107	122	93	96	116	95	96	105	114
June 20, 01	n/a	100	107	82	109	103	115	86	83	106	92	116	101	113
July 4, 01	-	71	71	55	69	67	79	68	62	73	59	65	66	76
July 23, 01	24	83	79	62	75	81	105	86	77	79	76	82	79	107
Aug 14, 01	51	86	79	61	70	77	105	68	69	83	74	78	73	107
Aug 27, 01	26	85	79	59	68	75	106	78	67	73	73	79	74	107
Sept 21, 01	18	86	78	57	68	75	110	75	64	69	66	77	68	109
May 24, 02	-	94	105	80	114	97	128	85	83	118	94	79	86	118
Jun 4, 02	11	95	103	71	101	95	120	82	76	110	92	81	86	117
Jun 18, 02	24	93	90	57	93	83	119	80	73	91	84	75	83	113
Jul 16, 02	50	85	75	58	65	72	102	73	61	61	64	73	72	101
Jul 29, 02	55	100	93	67	94	89	115	80	69	89	84	94	103	110
Aug 13, 02	28	94	88	74	90	89	111	82	73	81	81	96	101	112
Aug 27, 02	23	93	86	67	88	102	134	84	73	82	72	91	104	107
Sept 13, 02	34	105	96	77	95	97	118	85	81	97	82	101	108	117

* Meteorological record for SWSS began in July, 2001; cumulative since last measurement date

Table 2.3 TSW120 (mm) for each access tube location
Averaged across all four replicates.

Date	Ppt.* (mm)	Tubes												
		1	2	3	4	5	6	7	8	9	10	11	12	13
June 9, 01	n/a	336	318	224	298	369	430	192	197	206	179	135	206	444
June 20, 01	n/a	329	300	210	281	355	413	197	189	207	168	153	194	439
July 4, 01	-	290	258	178	227	314	382	166	172	167	133	97	145	387
July 23, 01	24	292	236	173	213	313	400	176	166	171	139	106	145	415
Aug 14, 01	51	283	228	167	202	310	405	178	157	142	131	100	136	406
Aug 27, 01	26	279	226	162	198	298	401	165	148	159	133	101	133	418
Sept 21, 01	18	279	226	155	186	300	409	150	133	142	118	98	123	420
May 24, 02	-	312	287	196	277	348	467	158	160	194	180	97	183	456
Jun 4, 02	11	303	293	187	265	350	427	152	163	191	166	100	174	446
Jun 18, 02	24	311	280	182	250	333	451	152	157	172	151	95	162	432
Jul 16, 02	50	297	230	155	186	312	418	145	132	126	119	92	138	414
Jul 29, 02	55	315	258	174	242	331	449	160	148	170	145	118	172	415
Aug 13, 02	28	310	249	183	240	339	439	161	153	160	144	121	173	429
Aug 27, 02	23	284	236	170	215	373	490	159	147	148	133	111	188	416
Sept 13, 02	34	312	257	188	247	342	438	167	160	177	145	129	180	424

* Meteorological record for SWSS began in July, 2001; cumulative since last measurement date

Table 2.4 TSW80-120 (mm) for each access tube location
Averaged across all four replicates.

Date	Ppt.* (mm)	Tubes												
		1	2	3	4	5	6	7	8	9	10	11	12	13
June 9, 01	n/a	108	111	46	94	141	157	19	25	23	53	9	55	171
June 20, 01	n/a	115	96	37	80	135	161	15	22	25	45	6	48	169
July 4, 01	-	105	93	39	74	135	155	14	23	19	44	7	39	163
July 23, 01	24	106	68	31	67	126	153	12	21	27	36	7	37	165
Aug 14, 01	51	95	69	30	65	127	158	34	24	4	34	6	34	157
Aug 27, 01	26	95	68	29	64	122	152	13	21	26	33	6	28	167
Sept 21, 01	18	94	76	26	57	125	156	11	17	18	32	7	31	169
May 24, 02	-	112	88	40	80	137	175	6	18	16	57	7	57	172
Jun 4, 02	11	105	92	39	80	142	148	5	18	17	49	6	48	172
Jun 18, 02	24	111	93	51	79	138	175	6	18	17	43	7	47	172
Jul 16, 02	50	108	74	29	63	139	169	9	18	16	36	6	37	170
Jul 29, 02	55	107	76	32	69	138	185	13	20	20	34	6	35	169
Aug 13, 02	28	108	73	29	73	140	177	10	20	19	36	6	37	174
Aug 27, 02	23	94	84	36	71	154	189	15	16	17	37	4	50	171
Sept 13, 02	34	99	77	36	75	135	169	15	18	16	36	8	38	167

* Meteorological record for SWSS began in July, 2001; cumulative since last measurement date

Table 2.5 Bulk density (Mg m^{-3}) with depth on August 27, 2002
Averaged across all four replicates.

Depth	Tubes												
(cm)	1	2	3	4	5	6	7	8	9	10	11	12	13
15	1.47	1.34	0.97	1.45	1.52	1.32	1.54	1.37	0.95	1.57	1.74	1.45	1.16
25	1.61	1.35	1.34	1.42	1.55	1.22	1.60	1.69	1.60	1.49	1.46	1.63	1.13
35	1.63	1.33	1.32	1.18	1.53	1.64	1.65	1.67	1.35	1.47	1.28	1.45	1.28
45	1.58	1.42	1.04	1.34	1.52	1.32	1.61	1.22	1.57	0.90	0.79	1.24	1.26
55	1.55	1.13	1.40	1.40	1.60	0.93	1.09	1.39	1.31	0.86	1.10	1.09	1.22
65	1.53	0.82	1.35	1.24	1.34	1.16	1.20	1.15	1.26	1.09	0.97	0.93	1.05
75	1.17	1.03	0.92	1.19	1.32	1.34	1.19	1.06	1.02	1.28	0.99	1.13	1.25
85	1.28	1.26	0.96	1.13	1.33	1.18	0.93	0.89	0.72	1.32	1.03	0.97	1.33
95	1.24	1.39	0.94	1.22	1.12	1.30	0.87	1.11	0.85	1.31	0.98	1.03	1.42
105	1.27	1.37	1.24	1.16	1.18		1.05	1.11	0.65	1.41	1.03	1.08	1.38
115	1.05	1.40	1.34	1.14	1.21		1.10	1.18	0.94	1.37	1.09	1.11	1.36
125	1.12		1.37	1.21			1.14	1.25	1.05	1.36	1.15	1.29	
135			1.33				1.16	1.25	1.09	1.45	1.29	1.24	
145			1.30				1.18	1.08	1.31	1.48	1.37	1.27	

Table 2.6 Percent saturation with depth, June 9, 2001 (wettest day)

Depth (cm)	TUBE												
	1	2	3	4	5	6	7	8	9	10	11	12	13
15	48	52	30	59	56	50	46	48	42	61	59	53	44
25	71	61	51	71	69	59	66	73	78	63	67	81	56
35	75	63	51	56	72	68	75	65	64	40	50	56	62
45	71	63	40	61	72	71	68	50	64	12	22	29	63
55	69	47	48	47	76	59	41	49	38	9	15	17	70
65	70	31	44	34	59	73	33	28	25	13	6	15	74
75	58	27	30	29	62	71	21	17	13	17	3	19	82
85	52	35	17	28	65	67	13	12	10	22	2	18	85
95	47	50	17	38	58	78	7	11	12	26	3	20	92
105	50	63	19	47	51		5	8	6	29	4	23	88
115	36	81	25	48	63		5	10	5	32	6	30	89
125	46		36	48			6	13	8	33	10	47	
135			47				9	15	9	36	16	58	
145			40				8	14	12	41	25	61	
155													

Table 2.7 Percent saturation with depth, September 21, 2001 (driest day)

Depth (cm)	TUBE												
	1	2	3	4	5	6	7	8	9	10	11	12	13
15	44	35	19	32	35	47	39	31	23	37	58	34	44
25	58	41	31	41	52	55	51	50	46	42	46	48	53
35	62	46	34	36	56	63	58	43	42	38	32	41	57
45	59	49	30	39	59	68	55	29	50	12	14	21	57
55	61	38	40	36	67	56	31	32	31	5	5	7	61
65	61	24	37	24	48	71	28	22	24	7	0	5	66
75	44	17	25	21	50	66	17	15	12	10	1	8	76
85	52	19	13	18	58	60	5	10	9	13	2	9	83
95	43	29	7	21	49	68	3	7	10	15	2	12	90
105	40	46	11	28	57		4	5	4	18	3	13	88
115	38	63	15	34	59		5	6	3	20	4	17	89
125	45		22	50			7	9	6	24	6	26	
135			31				10	13	8	29	11	36	
145			35				10	13	11	31	15	34	
155													

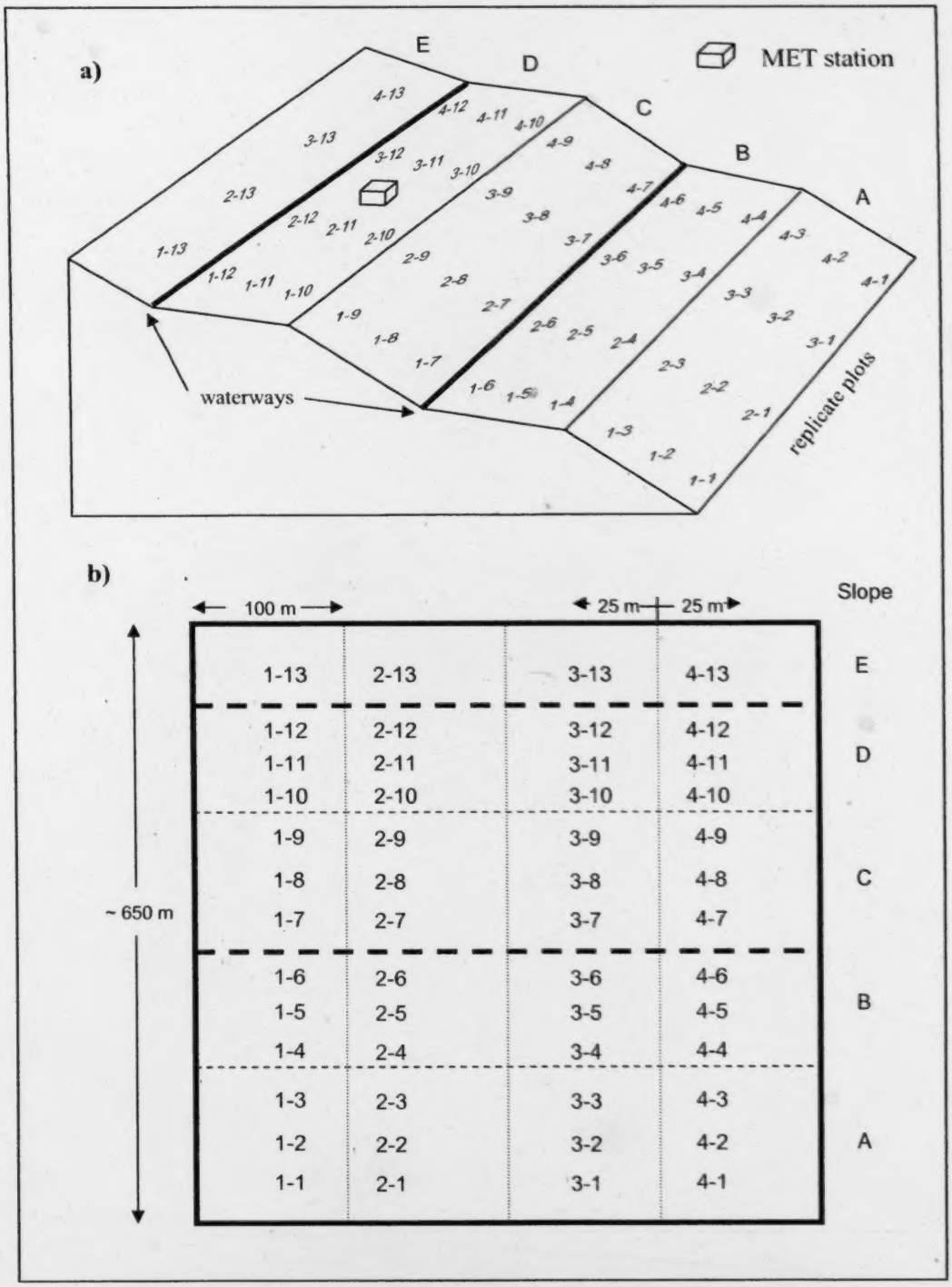

Figure 2.1 Layout of neutron access tubes a) 3-D schematic b) plan view
Tubes are numbered as: (transect (or replicate) number - tube number).
Bold horizontal lines represent the location of waterways.

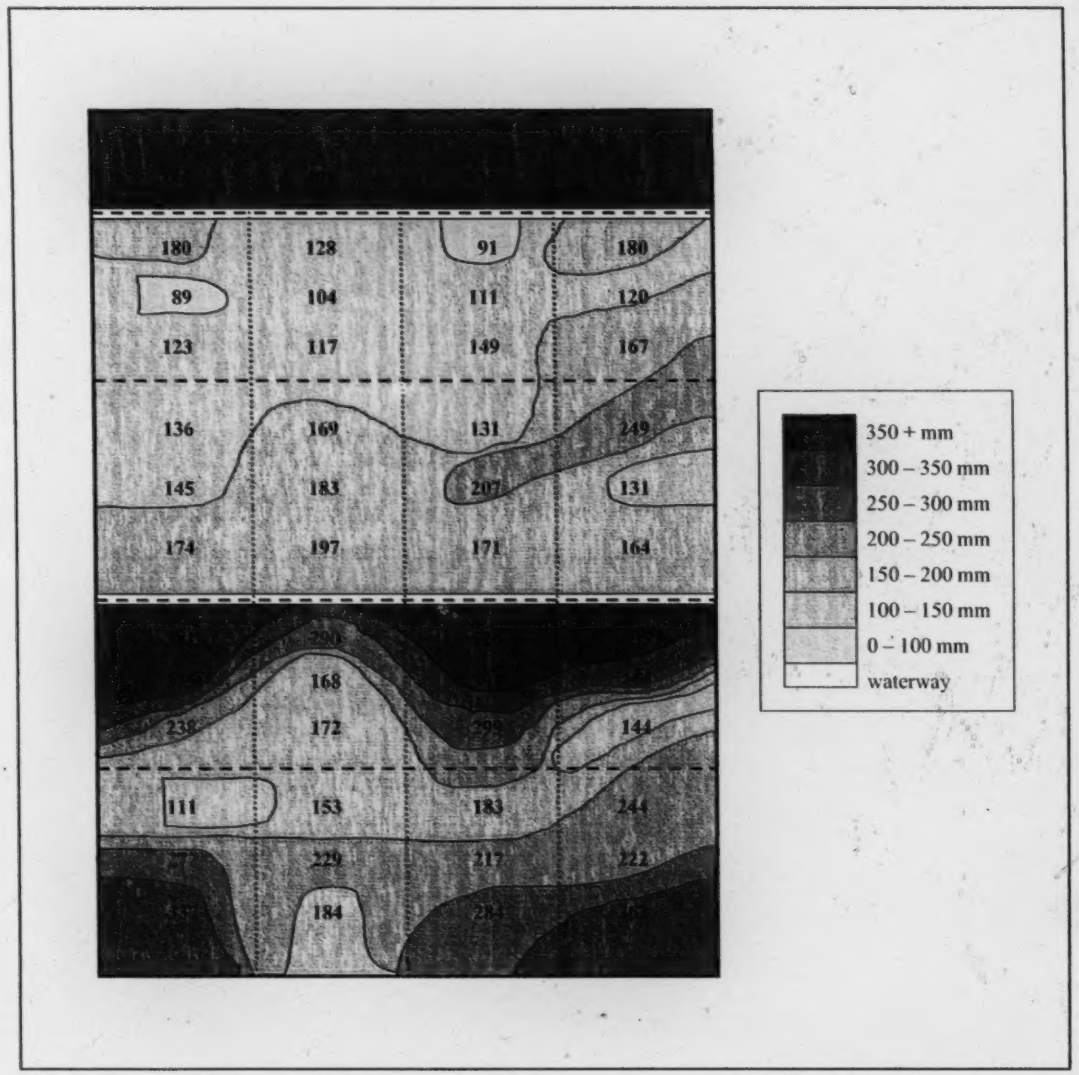

Figure 2.2 Plan view contour plot of Total Soil Water (mm) to a depth of 120 cm, July 23, 2001

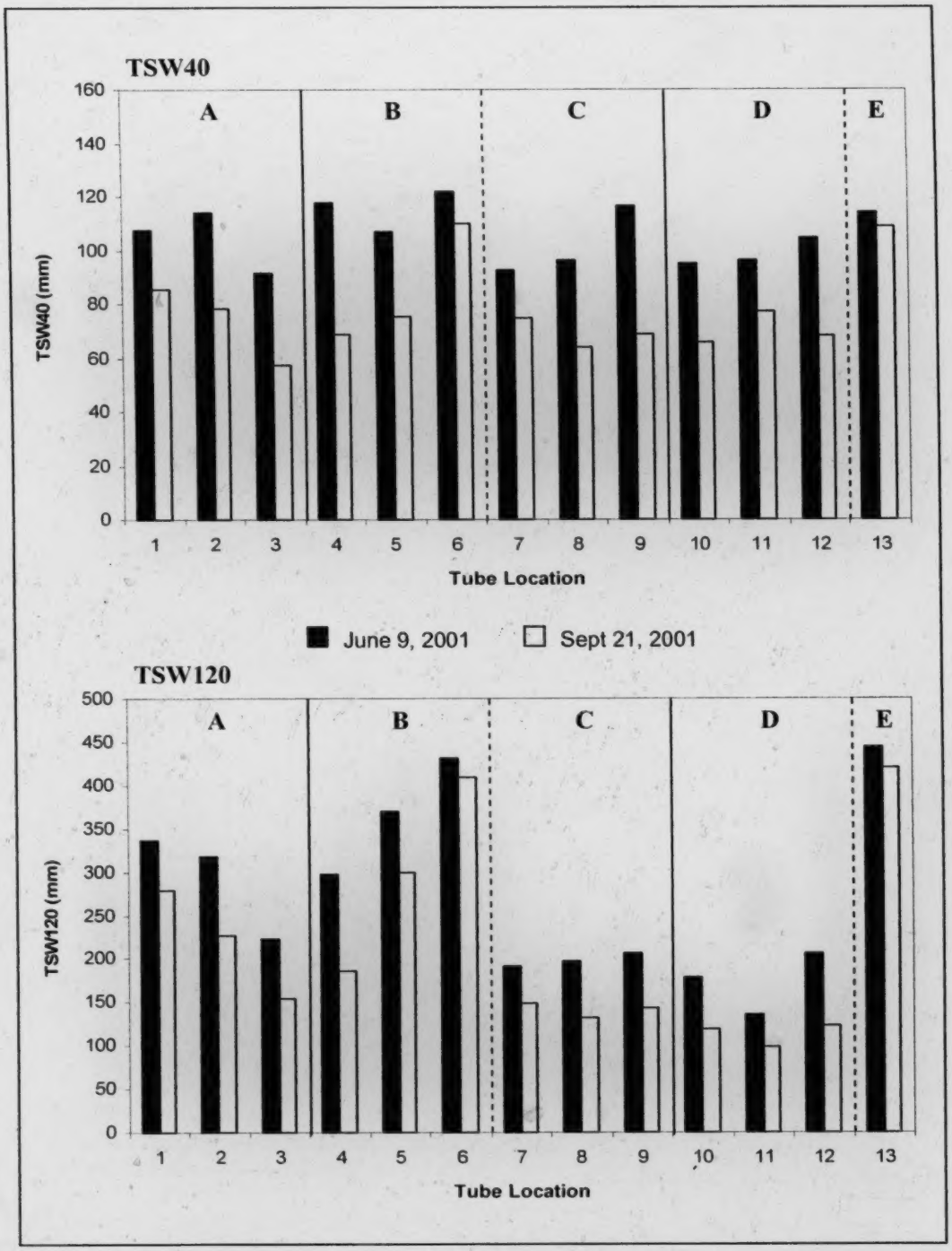

Figure 2.3 Total Soil Water to 40 and 120 cm (averaged across four replicates) June 9, 01 was a relatively wet day, Sept. 21, 01 was a relatively dry day. Solid lines represent crest locations, broken lines represent waterways. Labels A, B, C, D, and E denote slopes.

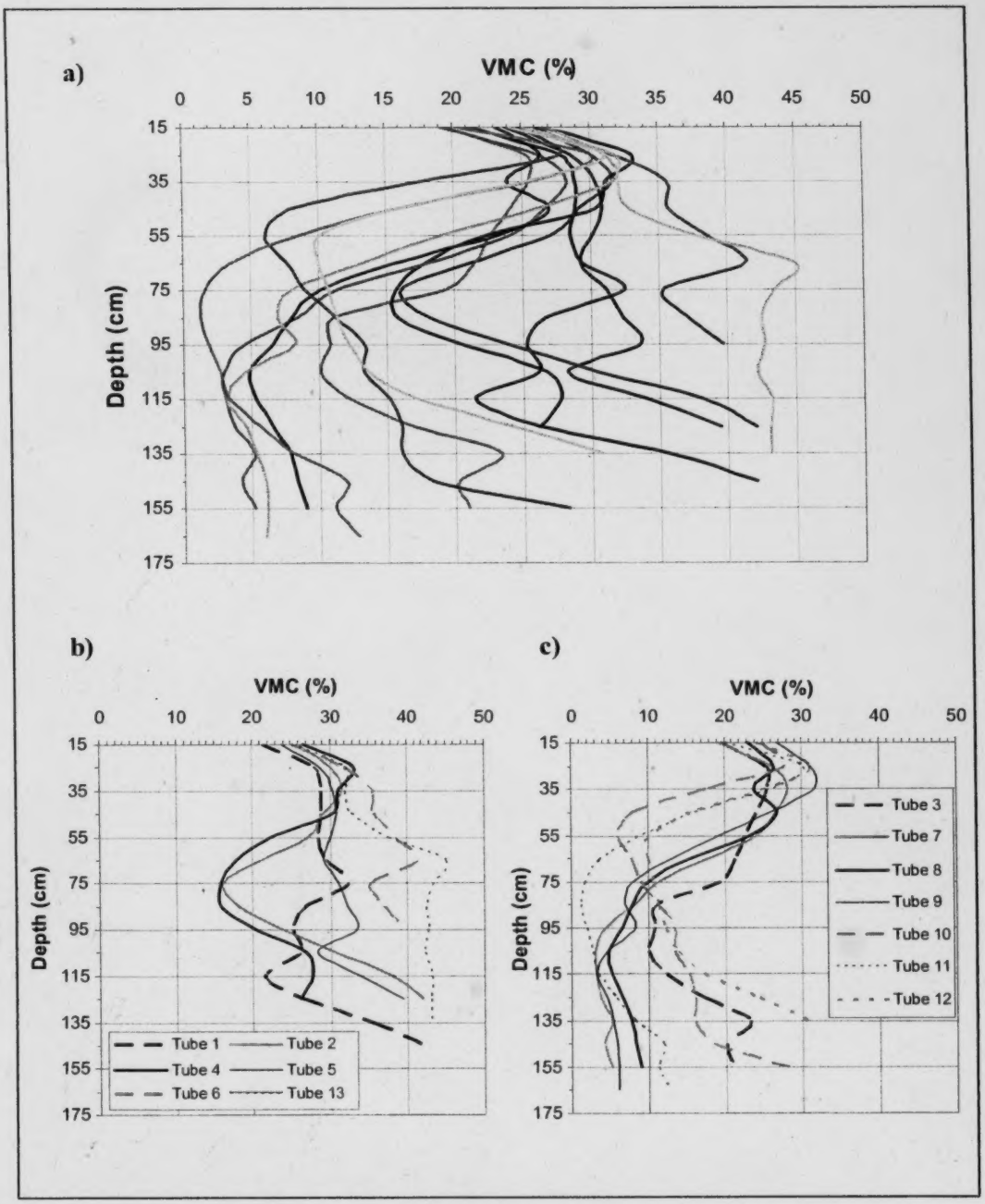

Figure 2.4 Volumetric Moisture Content (VMC) on June 9, 2001 (a relatively wet day)

a) Range of moisture contents measured across site (different lines represent the 13 neutron access tubes, averaged across 4 replicates)
b) VMC with depth for tubes 1, 2, 4, 5, 6, and 13 (the mid to wet tubes)
c) VMC with depth for tubes 3, 7, 8, 9, 10, 11, 12 (the dry tubes)

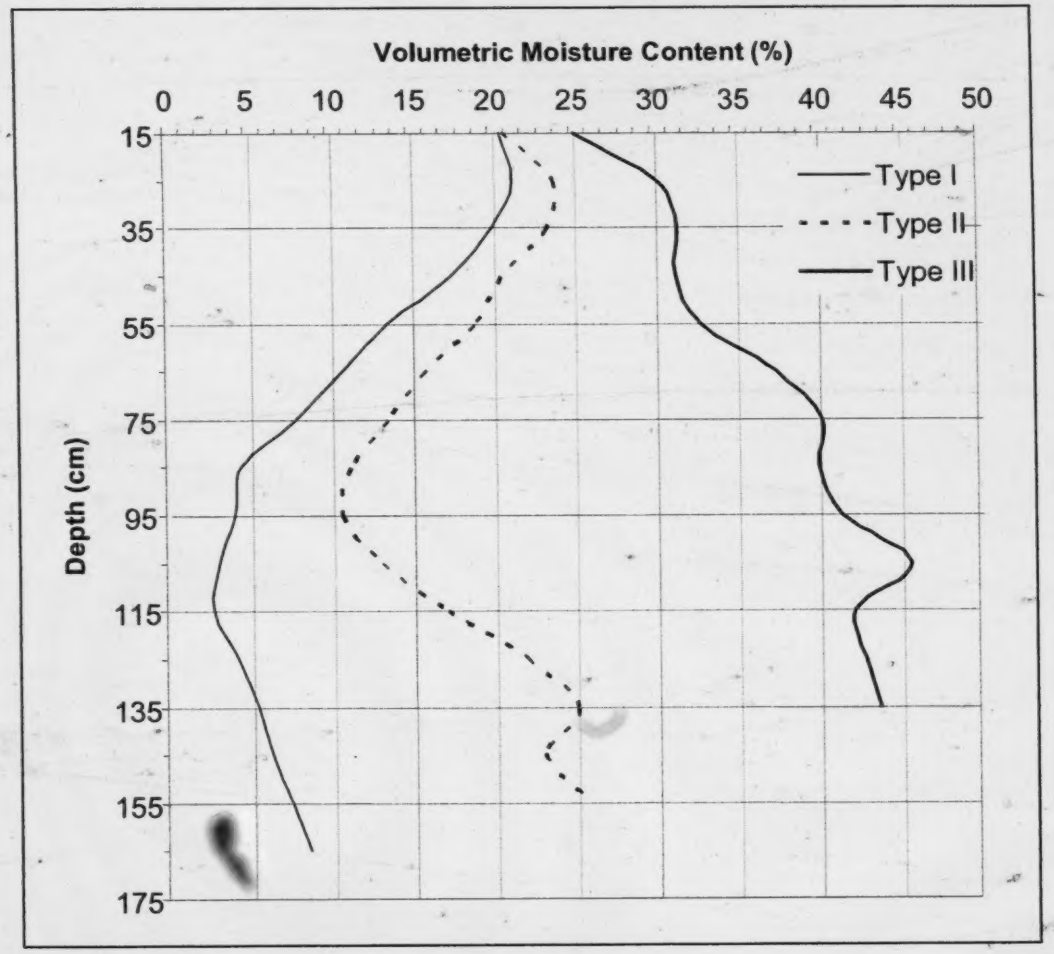

Figure 2.5 Three characteristic soil moisture profiles
Type I) drier areas, Type II) areas with moderate moisture, and Type III) wetter areas

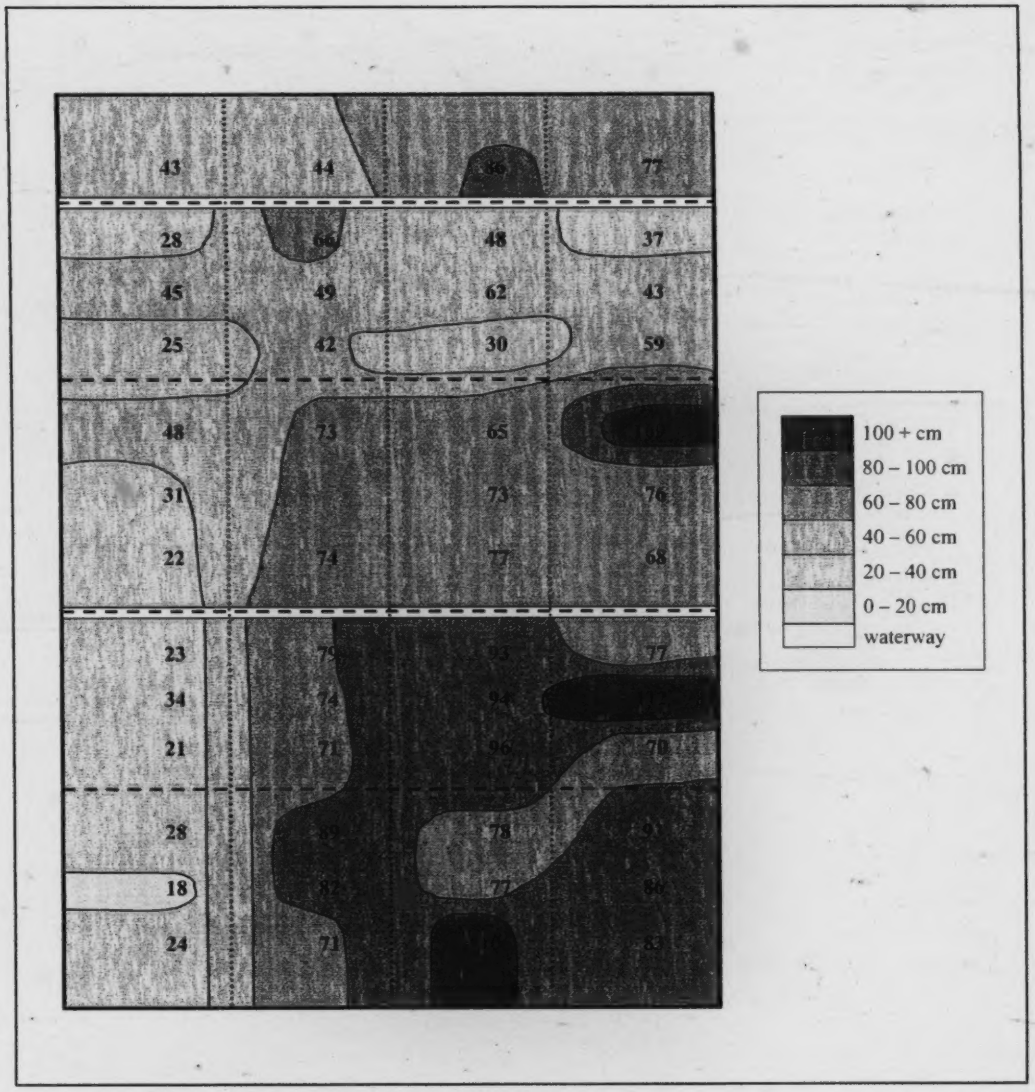

Figure 2.6 Variation in topsoil depth, by replicate plot
An interface depth could not be measured at location 2-8.

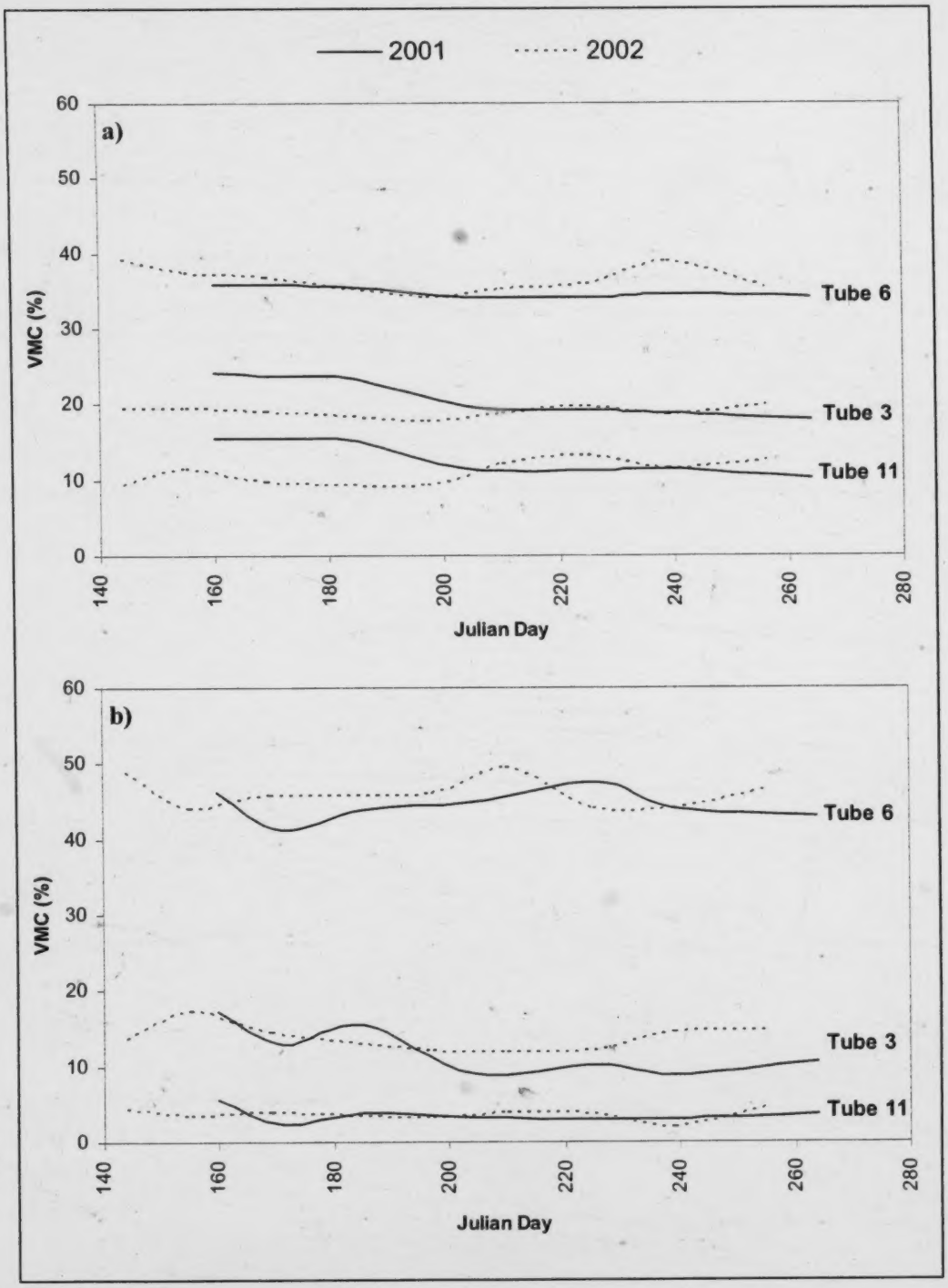

Figure 2.7 Trends in soil moisture over time a) at a depth of 40 cm b) at a depth of 120 cm
(averaged across all four replicates)

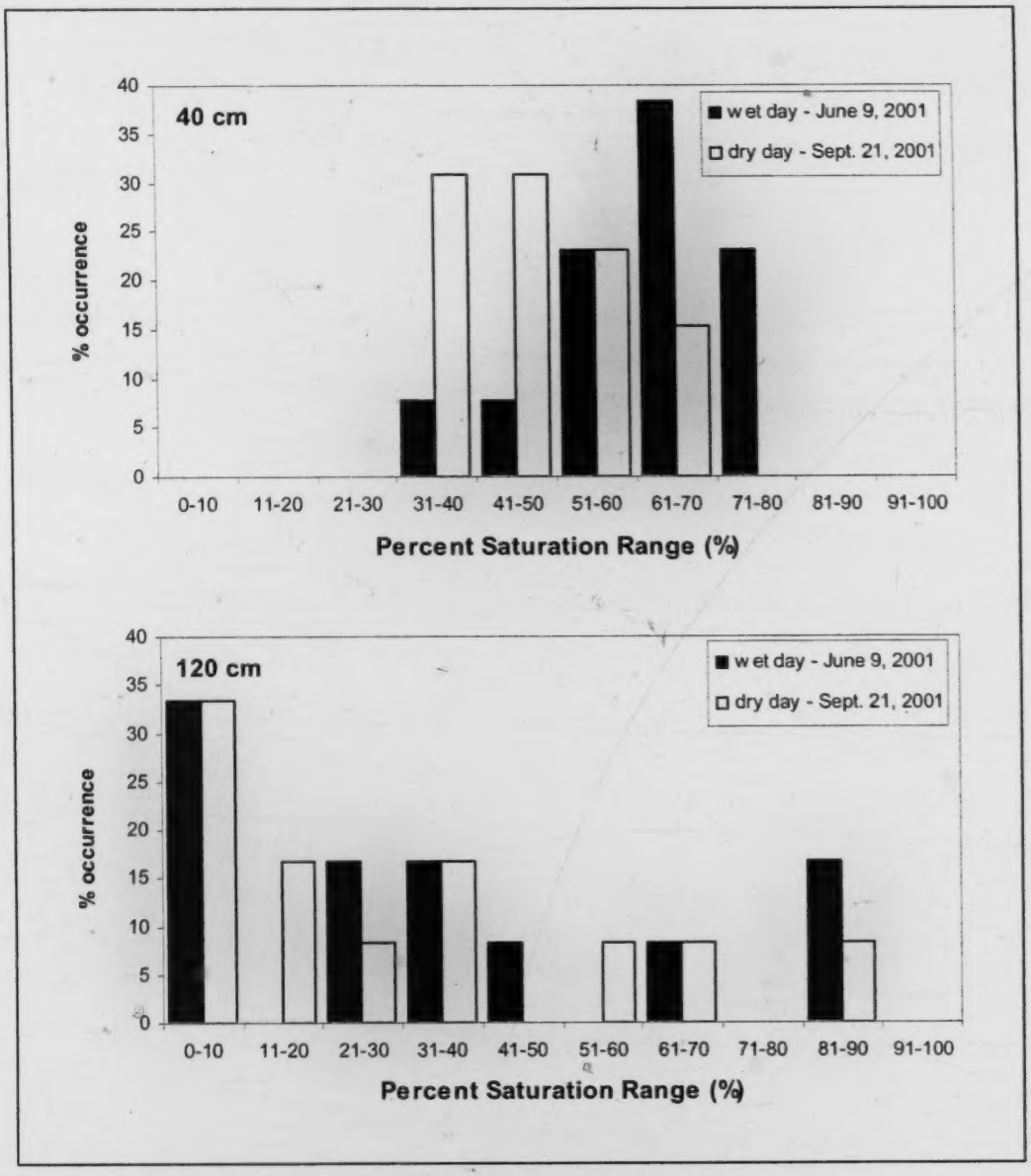

Figure 2.8 Histograms of percent saturation at 40 cm and 120 cm
Illustrates how often particular degrees of saturation are met.

2.6 References

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3.0 SOIL MOISTURE REGIME IN A COMPLEX SOIL PROFILE (AT THE TOPSOIL-TAILINGS SAND INTERFACE)

3.1 Introduction

The interface between the topsoil and tailings sand on the SWSS introduces a textural discontinuity in the soil profile; with finer clay loam topsoil placed directly above coarser tailings sand. It is valuable to know how soil moisture changes with time at this interface, and to compare the different soil moisture dynamics above and below the interface (in the two different materials).

Theory suggests that in a layered soil profile, one in which a finer textured soil overlies a coarser one, water accumulates above the interface in the fine textured soil (Alway and McDole 1917, Day and Luthin, 1953, Eagleman and Jamison 1962, Aylor and Parlange 1973, Stauffer and Dracos 1984). This effect, sometimes referred to as the "fluid retention effect" (Stauffer and Dracos 1984), occurs because water must flow from small pores to larger pores, which will not happen until the potential of water (or suction) in the fine-textured soil reaches that which is comparable to the large pores (normally near saturation in the finer soil) (Aylor and Parlange 1973). Therefore, such a textual discontinuity becomes a barrier to downward or upward water movement, despite a small flux of water vapour (Aylor and Parlange 1973), until the soil becomes nearly saturated. Under these conditions, more water remains in the root zone, and subsequently a stratified soil can hold more water for plant use than could uniform soils (Gardner 1968). However, Eagleman and Jamison (1962) found that there is no restriction in water movement across the discontinuity if the differences in pore size are not extreme (and if the pore volumes are comparable).

If the soil above a textural discontinuity becomes saturated, lateral flow (interflow) is possible. If this occurs at a gently sloping site, water may move laterally down slope at the interface between the two layers (Chanasyk 1980).

The Southwest Sand Storage Facility consists of tailings sand directly overlain with finer textured clay loam topsoil, which creates a textural discontinuity at the topsoil-tailings sand interface. Of course, natural soils do not normally have abrupt contacts such as is the case at the SWSS, so this introduces an important hydrologic factor, which will govern moisture movement in the soil profile. Moskal (1999) studied the moisture characteristics of a peat-mineral mix over tailings sand (using soils from the Athabasca oil sands), as part of a column experiment, and found that moisture dramatically decreased below the interface between the peat-mineral soil and tailings sand.

3.2 Objectives

The main objective of the study was to characterize soil moisture dynamics in the vicinity of the topsoil/tailings sand interface, and specifically to answer:

i. How does soil moisture vary over time near the surface?
ii. How does soil moisture vary over time on either side of the topsoil-tailings sand interface?
iii. How does soil moisture near the interface respond to soil moisture fluctuations at the surface?

3.3 Materials and Methods

Time-Domain Reflectometry was used to investigate the change in soil moisture with time, at the surface and just above and below the interface between tailing sand and topsoil. A pressure plate analysis was also performed (using soil samples taken 3 m to the left of each neutron access tube) to derive characteristic curves for the topsoil and tailings sand.

3.3.1 Time-Domain Reflectometry

Time-domain reflectometry (TDR) is an in situ (indirect) method of measuring soil moisture. TDR measures the time for an electromagnetic wave to pass through a

known length of medium, with the travel time being dependent on the dielectric constant of the medium (Spittlehouse 2000). The signal's travel time is strongly dependent on soil moisture content because water has a much higher dielectric constant than dry soil (Topp 1988). In this respect, a signal would take longer to travel through water than through soil, since the velocity of propagation is decreased in materials of higher dielectric constant (Topp 1993).

In this study, TDR probes were used to measure soil moisture dynamics at the surface, and in the vicinity of the topsoil-tailings sand interface. They were chosen because of their ability to measure soil moisture with time over very small time steps (through the use of a data logger) and the ease of operation (instrument gives direct readout in volumetric soil moisture content). The TDR probes were Campbell Scientific 615 probes (CS615), consisting of two parallel, stainless steel rods, which are 30 cm long, 3.2 mm in diameter and spaced 3.2 cm apart. These rods act as a wave guide for the electromagnetic pulse.

In June 2001, 36 TDR probes were installed on the instrumented watershed in Replicates 3 and 4 on the first slope and backslope (Figure 3.1a). Three TDR probes were installed to each of 12 locations. At each location (or 'nest'), the first probe was inserted at a 45-degree angle into the upper 15 cm of topsoil, the second horizontally into the topsoil 10 cm above the interface, and the third horizontally 10 cm below the interface in the tailings sand (Figure 3.1b). Pits were dug to facilitate the insertion of the two lower probes and then were carefully backfilled. The depth to interface varied at each of the TDR nests (Table 3.1), ranging from 70 – 95 cm. The distances to each of the 12 nests, from the central data logger, are given in Table 3.2.

The probes were calibrated in a laboratory using soil from the site. Data were collected from all 36 sensors using a data logger (CR10) every 5 minutes and averaged. The monitoring of soil moisture over time was designed to quantify the 1-D dynamics (vertically) at the measurement location as well as the spatial variability among locations. Averaged TDR data were measured on an hourly basis between

July – September, 2001 and March – September, 2002. A gap exists in the data between July 23 – Aug 17, 2001 (inclusive), when data logger complications were experienced in the first field season.

Precipitation data were obtained from the meteorological station (Tables 6.1 and 6.2 in the Appendix) situated on the SWSS instrumented watershed (upper-mid site) as shown in Figure 3.1a.

3.3.2 Statistical Analysis

Due to the tremendous amount of TDR data (two field seasons of hourly data, for 36 probes) it was not possible to run a statistical analysis on the entire data set. Instead, the major rainfall events were identified from 2002 (insufficient data in 2001), and a statistical analysis was performed over separate 2- or 3-day periods. Six rainfall events were chosen for analysis and these data are provided in the Appendix (Table 6.7). The main purpose of this analysis was to determine if there is significant variation between the 12 different nest locations (e.g., comparison between all 12 surface probes), and to determine if there is significant difference between the forward slope and backslope positions.

A univariate split-plot design was chosen to analyze the TDR data, with TDR nest site, date, and hour being the sources of variation. The statistical analysis (performed using SAS statistical software) was set up according to the following statistical model:

$$Y_{ij} = \mu + \alpha_i + \delta_j + (\alpha\delta)_{ij} + \gamma_k + (\alpha\gamma)_{ik} + (\delta\gamma)_{jk} + \varepsilon_{ij}$$

where Y_{ij} = observed soil moisture

μ = overall mean

α_i = effect of TDR nest location (1, 2, 3, …, 12)

δ_j = effect of date (1 – 2, 3, or 4; depending on precip. event)

$(\alpha\delta)_{ij}$ = effect of interaction between nest and date

γ_k = effect of hour (1, 2, 3, …, 24)

$(\alpha\gamma)_{ik}$ = effect of interaction between nest and hour

$(\delta\gamma)_{jk}$ = effect of interaction between day and hour

e_{ij} = experimental error (nest*day*hour interaction)

The TDR data were tested according to this model for each of the 6 rainfall events individually. The point here was not to test for variation between the different days or hours, but only variation among TDR sensors. A contrast was set up to test for variation between the forward and backslope (i.e., nests 1 – 6 vs. 7 – 12), and a Tukey adjustment was used to test for significant difference between each of the 12 nest locations (for the surface, above interface, and below interface positions separately). In all statistical analyses, a confidence level of 95 % ($\alpha = 0.05$) was chosen to distinguish statistically significant variation.

3.4 Results and Discussion

3.4.1 Soil Moisture Trends and Variability

Results of the pressure plate analysis (characteristic curves) are given in the Appendix (Figure 6.4). The most notable outcome from the pressure plate analysis was discovering that the tailings sand, once dry, cannot be wetted, suggesting that the tailings sand onsite may be hydrophobic.

The greatest variation in soil moisture over time was found near the surface, with very little variation just above the interface, and also little variation below the interface in the tailings sand (Figure 3.2). Only TDR data from 2002 are illustrated in Figure 3.2, because TDR data from 2001 spans only July – September.

In general, soil moisture was greatest above the topsoil-tailings sand interface, followed by soil moisture at the surface (Figure 3.2). The probe below the interface measured the lowest soil moisture values, as expected given the coarseness of the soil (tailings sand) at this location. In a few instances, however, the probe below the

interface measured soil moisture contents as high, or higher than surface values. This occurred at nest locations 3 and 4 (the locations closest to the first water way), around access tube locations 3-5 and 4-5. Soil moisture values for the below-interface probe at location 3 exceeded those for other sensors between May – June, exhibiting a large peak in soil moisture in Figure 3.2.

Soil moisture on the backslope was significantly different from that on the forward, with the backslope generally being wetter. Results of the statistical analysis are given in the Appendix (Table 6.8). The greatest variation between the forward and backslope is found below the interface; volumetric moisture on the forward slope ranged from 4 – 16 % and volumetric moisture on the backslope ranged from 3 – 44 % (Figure 3.2). The surface probe at TDR nest 12 was significantly different from all other probes (exhibiting lower moisture contents and a lack of response to precipitation (Figure 3.2)), therefore it was removed from the statistical analysis. The other two probes at location 12 (above and below interface) remained in the analysis.

Generally, when the surface responds to precipitation events, the other two (deeper) probes do so either in a muted fashion, or not at all. A peak for spring melt is evident in mid-May 2002, during which moisture increased above the interface (approximately May 17) and moisture below the interface responded with a 3-day lag (approximately May 20) (Figure 3.2). At the surface, most of the moisture peaks during the summer were greater than those post springmelt, suggesting that snowmelt infiltration water has a lesser effect on surface soil moisture.

3.4.2 Soil Moisture with Time

Soil moisture just above the interface slowly increased over the 2002 field season (Figure 3.2), which indicates that water is draining downward from the surface, and collecting at the topsoil-tailings sand interface. This response is not unusual considering the textural discontinuity present at the interface. Below the interface, soil moisture remained fairly constant over the field season at most locations, with only two locations (2 and 6 on the backslope) exhibiting response to rainfall events

(Figure 3.2). TDR locations 3, 4 and 8, below the interface, exhibit a large peak in moisture around May 19. Soil moisture at location 3 continued to increase following snowmelt, while that at locations 4 and 8 gradually decreased throughout the rest of the season; these locations seem to have had heightened responses to snowmelt infiltration.

There appears to be no net movement across the topsoil-tailings sand interface (i.e., movement downwards largely equals movement upward) with the textural difference acting as somewhat of a barrier, causing water to collect above the interface. There is the possibility of lateral movement of water at the interface (interflow), as water retention just above a textural discontinuity is normally heightened in this type of situation (Chanasyk 1980). In this case, however, lateral transmission is not likely, being that moisture conditions in the topsoil and in the vicinity of the interface are not very high (according to neutron probe data, see section 2.4.3).

Figure 3.3 shows soil moisture for each field season for two TDR nest locations, which were found, statistically, to be near the mean (see statistical results, Appendix Table 6.8) and therefore chosen to be representative of the entire data set. These two nest locations are nest 6 (on the backslope) and nest 11 (on the forward slope).

The TDR data collected from June to September in 2001 were quite similar to 2002 data for the same time period (Figure 3.3). There was less rainfall in 2001 (see Figure 2.2), which resulted in a lack of moisture variations at the surface in that year. In the second year (2002) more rainfall was received, and consequently soil moisture conditions were slightly wetter at the surface than in 2001. The moisture values in the tailings sand (below the interface), however, did not change from the previous year, but were consistently low over both seasons (3 – 5 % moisture by volume). This is not unusual, considering the relatively short time scale being considered. The two probes near the interface did, however, respond to the May springmelt, and in some locations, they also showed response to major rainfall events (Figure 3.3a). The

below-interface probe at nest 6 responded to most major rainfall events, while nest 11 did not.

When comparing Figure 3.3 with Figure 2.7 (in section 2), the surface TDR probes behave most like neutron access tube location 3 (which is just below the center of the TDR layout in Figure 3.1), which had a volumetric moisture content of approximately 20 % at a depth of 40 cm. The TDR probes at the surface, however, measured much more variation over time than did the neutron probe at 40 cm below the surface (likely a result of only intermittent, fair weather measurements with the neutron probe). To contrast the lowest TDR probes in Figure 3.3 with tube location 3 in Figure 2.7b (a depth of 120 cm), the TDR probe beneath the interface measured lower moisture (5% vs. approximately 10 % measured with the neutron probe) and showed much less variation over time than the neutron probe measured at a depth of 120 cm.

Over the winter (between September 16, 2001 – March 20, 2002), soil moisture changed little at the surface (Figure 3.3); it decreased from 23 – 16 % at nest 6, and from 18 – 13 % at nest 11. Soil moisture below the interface remained unchanged from the end of the first field season to the start of the second; decreased from 4 – 3 % at nest 6, and remained 5 % at nest 11. Above the interface, however, volumetric soil moisture decreased 10 % (absolute VMC) from September 2001 – March 2002 (i.e., 30 – 20 % at nest 6, and from 28 – 18 % at nest 11). This "lost" moisture was likely used by vegetation or it may have moved laterally, as the below-interface probe does not appear to receive it.

3.4.3 Soil Moisture Response to Precipitation

The TDR data, along with precipitation data obtained from the meteorological station on site, were used to track how soil moisture (at the surface, and just above and below the topsoil-tailings sand interface) responded to specific precipitation events. A total of 5 precipitation events were analyzed (events June 28 – 29 and June 30 – July 1, 2002, as per the statistical analysis, were combined as one event for this investigation). The total precipitation amounts for the five rainfall events varied from

14.0 – 33.0 mm (Table 3.3). The time scale of the precipitation data from the instrumented watershed did not originally match the soil moisture response; i.e., soil moisture peaked before each rain event, with precipitation peaks always having the same general lag. This was attributed to either a difference in data logger clocks between the TDR probes and the meteorological station on site, or a difference in laptop clocks (as different computers were used to download the two data loggers). To account for this, all precipitation events in this investigation were adjusted ahead 22 hours, to match the peaks in soil moisture. As a result, soil moisture response to precipitation will be discussed in general, without comparing the time of soil moisture response with respect to precipitation.

To illustrate soil moisture response to precipitation, one rainfall event was chosen (July 19 – 20, 2002), and the TDR response from nest 6 and 11 (previously used as average, representative nests from the backslope and forward slope, respectively) were graphed over time (Figure 3.4). Approximately 26 mm of precipitation was collected at the meteorological station during a 19-hour period (Table 6.7 in the Appendix). Figure 3.4 shows the precipitation over the period and the response in soil moisture at the three TDR probe locations (surface, above interface, and below interface).

An increase in soil moisture was evident at the surface following the onset of precipitation (on July 19, 2002). This was more evident at nest location 11 (9.7 % increase in volumetric soil moisture) than at nest location 6 (4.1 % increase in volumetric soil moisture). At nest location 6, however, soil moisture increases both above and below the interface. No response to the rainfall event is seen around the interface at nest 11. At nest 6, the quickest rise in volumetric soil moisture occurred at the surface (a 4.1 % absolute increase over 7 hours = approx. 0.6 %/hr), followed by above the interface (a 2.1 % absolute increase over 5 hours = approx. 0.4 %/hr), with soil moisture below the interface taking the longest to peak (a 1.9 % increase over 10 hours = approx. 0.2 %/hr). At nest 11, surface soil moisture increased 9.7 %

over 16 hours, which is a rate of increase of approximately 0.6 %/hr (the same rate of soil moisture increase at the surface for nest 6).

A lack of significant response in below surface soil moisture to precipitation could be explained by the overall dry conditions of the site and the dry conditions of this area over 2001 – 2002 (see Table 2.1). Vegetation is likely utilizing most of the water added via precipitation, especially in the case of sporadic rainfall events, such as were the common occurrence in 2001 and 2002 (Figure 6.2 in the Appendix).

For each of the 5 precipitation events investigated, the change in soil moisture at the surface (from the point of minimum soil moisture before the rainfall event to the point of maximum soil moisture) was recorded (Table 3.4). Most of the surface probes had similar responses to each precipitation event, with standard deviations ranging from 2 – 5 %. In comparing the average soil moisture gain over each precipitation event to the amount of precipitation for that event (average soil moisture gained divided by total precipitation for a particular storm), the surface infiltrates between 30 – 60 % of the added precipitation, with more rainfall infiltrated near the beginning of the summer (June) than at the end (September) (Table 3.4). The proportion of runoff can also be estimated by subtracting percent infiltration from 100 % (Table 3.4). For the area where the TDR sensors are installed, runoff accounts for approximately 40 – 70 % of the incident precipitation. In comparison to other areas on site, however, there is less vegetation around the TDR sensor locations (the first crest), which may contribute to more runoff in this location.

The change in volumetric moisture content at the surface (moisture gained) during the 5 precipitation events was plotted against the antecedent (minimum) volumetric moisture content for each event (using all surface probes, Figure 3.5). Both a linear and quadratic model was used to fit the data, with the quadratic model fitting only slightly better than the linear (R^2 of 0.72 for the quadratic vs. 0.66 for the linear model). Overall, there is a reasonably good linear (inverse) relationship between antecedent moisture conditions and the moisture gained at the surface, in response to

a precipitation event. This result is expected and widely accepted in the literature (Chanasyk 1980); the storage potential of the soil decreases as antecedent moisture increases.

3.4.4 Replication

The statistical analysis revealed that the 12 nest locations are a statistically significant source of variation in soil moisture. Results of the statistical analysis are given in the Appendix (Table 6.8). Data from the surface probe at nest 12 was removed from the statistical analysis, as it was significantly different from all other surface probes and it had a lack of trend or response in comparison to the other surface probes, indicating most likely a sensor malfunction.

The 12 TDR nest stations captured great spatial variation in volumetric soil moisture on a relatively small area on site. From the coefficient of variation (CV), the below interface probes were the most variable (CVs of 86 – 107 %) and the surface and above interface probes were more consistent (surface CV of 7.4 – 15 %, above interface CV of 12 – 13 %). The main reason for the variation between probes below the interface was the very high moisture contents below the interface at nests 3 and 4 (nearest the waterway); all other locations were rather dry below the interface.

The backslope (nests 1 – 6) and forward slope (nests 7 – 12) were statistically different, with the backslope being wetter than the forward slope (Figure 3.2). The wettest nest locations were 2, 3 and 4 (on the backslope) and the driest locations were nests 7, 9 and 10 (on the forward slope). There seems to be a correlation between nest location and moisture status (wetter near the waterway, drier on the forward slope), as supported by the neutron probe data. For each of the three probe positions (surface, above and below interface), the general trends or patterns over time were similar for all nest locations (Figure 3.2), even if the relative magnitudes differed.

3.5 Conclusions

The textural discontinuity present in the soil profile (finer textured topsoil overlying coarser tailings sand) appears to restrict flow across the interface, with soil moisture just below the interface being very low and changing little over time. Soil moisture above the interface was greatest, and increased slightly over a field season. This suggests that water is draining from the surface and collecting above the interface, a result that is well documented in the literature for such textural discontinuities.

The TDR data from this study confirm that as antecedent moisture increases, the gain in moisture at the surface, following a precipitation event, decreases. At the topsoil-tailings sand interface, there was little response to infiltration at the surface, especially below the interface. The lack of response may be due to the dry conditions of the site in the past few years; the vegetation is likely utilizing moisture as soon as it becomes available, leaving less to markedly change soil moisture conditions at depth.

Table 3.1 Depth to interface (topsoil depth) at each TDR nest position

	TDR Nest Position											
	1	2	3	4	5	6	7	8	9	10	11	12
Topsoil Depth (cm)	75	90	85	80	70	n/a*	85	90	93	95	90	n/a*

* n/a denotes areas where interface depth was not recorded

Table 3.2 Distance of TDR nests to data logger

	TDR Nest Position											
	1	2	3	4	5	6	7	8	9	10	11	12
Distance to Datalogger (m)	26	14	28	14	25	13	28	28	28	27	28	27

Table 3.3 Total precipitation (mm) from major rainfall events on the SWSS in 2002

Jun 5-6, 02	Jun 29 – Jul 1, 02	Jul 19, 02	Jul 29-10, 02	Sep 2-3, 02
14.0	33.0	25.7	19.8	24.4

Table 3.4 Change in soil moisture (depth of 0 – 15 cm, mm) over major precipitation events in 2002

Nest #	Precipitation Events				
	Jun 5 – 6	Jun 28 – 30	Jul 19	Jul 29 – 30	Sep 2 – 3
1	5.4	8.9	5.4	3.3	6.0
2	8.9	21.2	6.0	4.7	4.8
3	6.9	17.4	10.5	5.6	9.0
4	7.4	11.9	11.9	8.0	10.4
5	9.5	10.5	7.4	3.3	6.8
6	5.1	9.9	7.1	4.7	7.5
7	8.0	12.6	7.1	6.3	10.2
8	7.7	12.8	12.0	8.6	11.1
9	11.0	21.8	14.4	7.7	16.4
10	9.8	16.7	13.4	6.6	9.8
11	9.5	19.2	14.6	10.5	6.9
Ave	8.1	14.8	10.0	6.3	9.0
Stdev	1.8	4.6	3.5	2.3	3.2
CV (%)	22.7	31.3	34.9	36.1	35.4
storm precip.	14.0	33.0	25.7	19.8	24.4
% infiltrated	57.7	44.8	38.7	31.7	36.8
runoff coeff. (%)	42.3	55.2	61.3	68.3	63.2

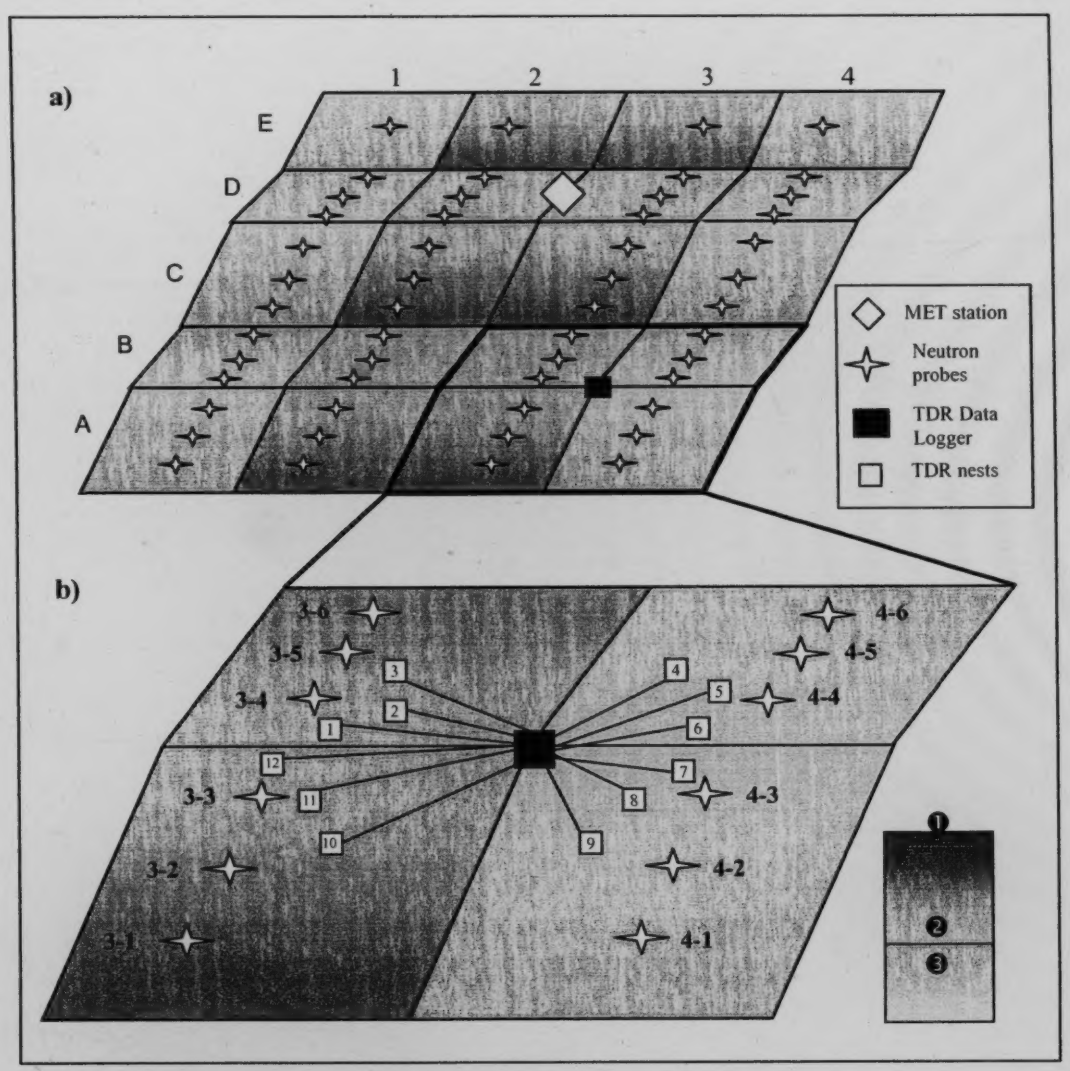

Figure 3.1 Schematic layout of TDR probes
a) location of TDR data logger on site b) location of TDR 'nests' and placement of the three TDR sensors in each nest

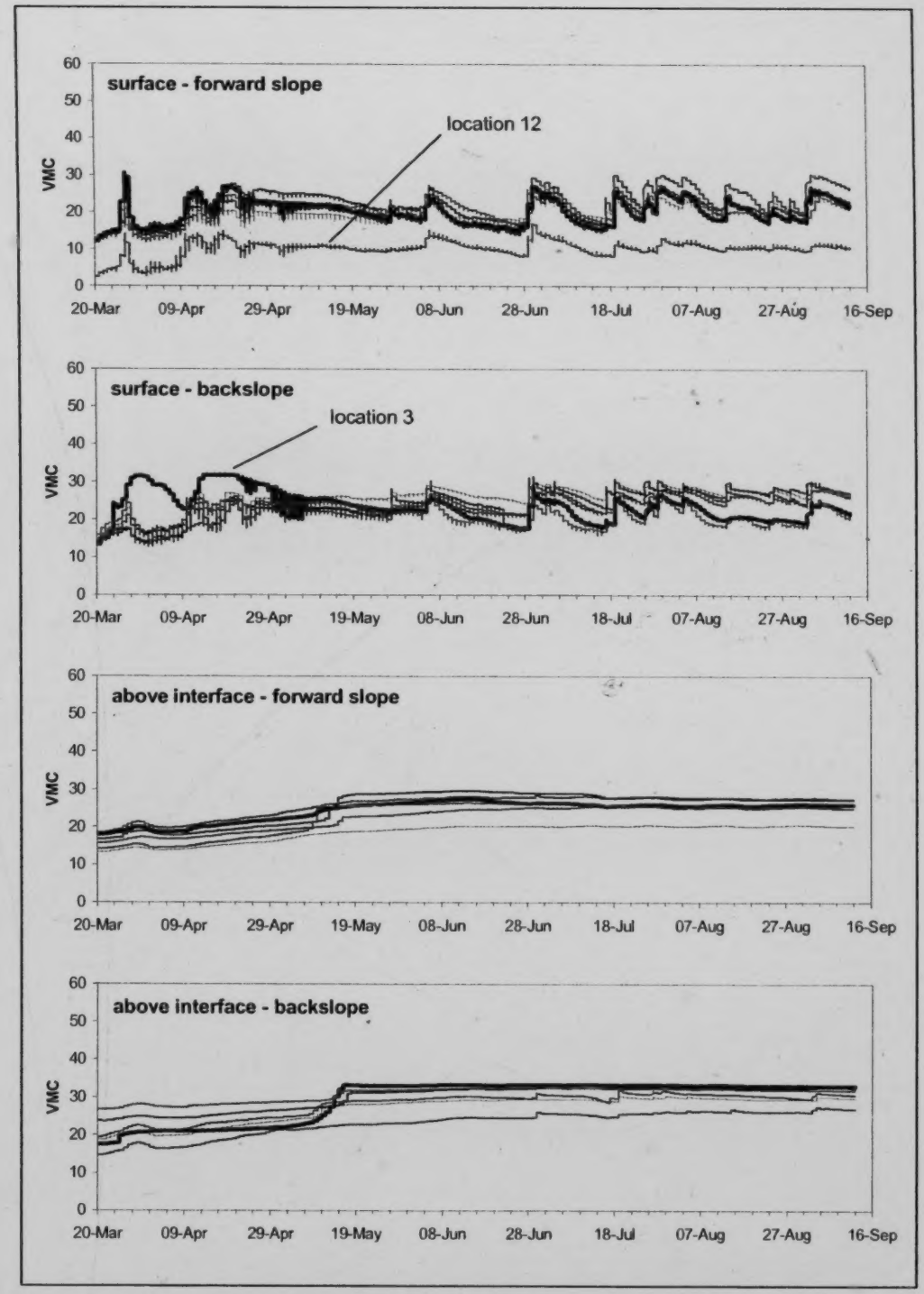

Figure 3.2 Variation in volumetric soil moisture over the 2002 field season
Six sensors plotted per graph (sensors 1-6 for the backslope, sensors 7-12 for the forward slope) to show relative trends and variation with time.

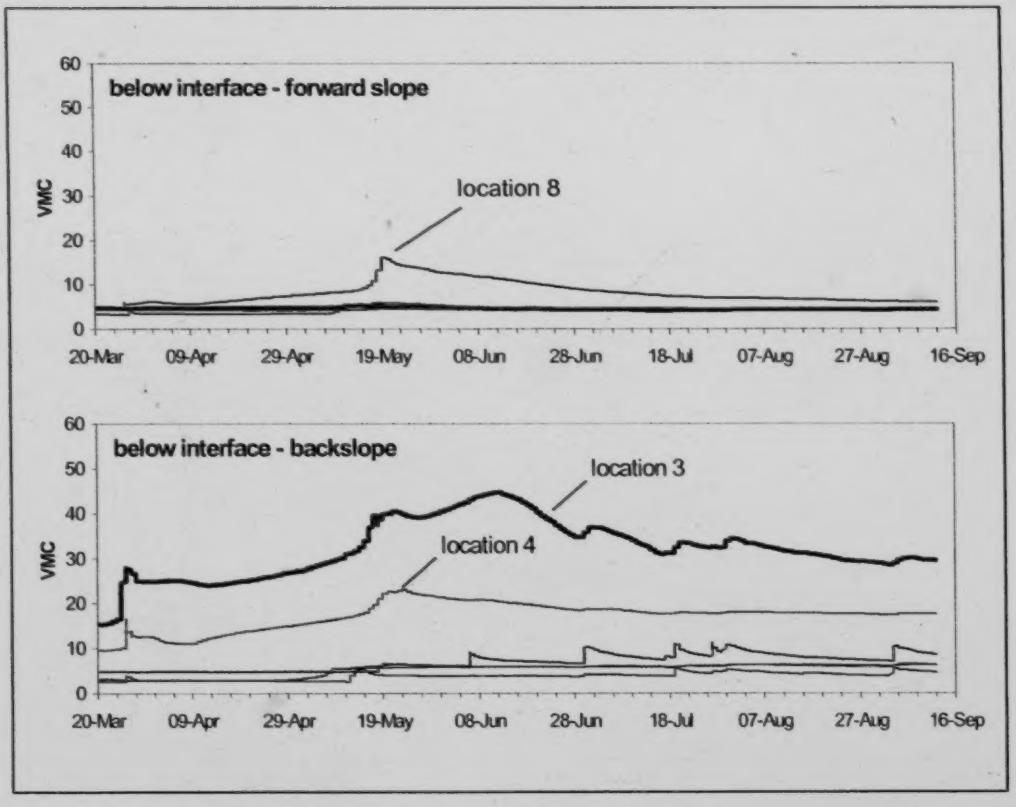

Figure 3.2 (continued)
Variation in volumetric soil moisture over the 2002 field season
Six sensors plotted per graph (sensors 1-6 for the backslope, sensors 7-12 for the forward slope) to show relative trends and variation with time.

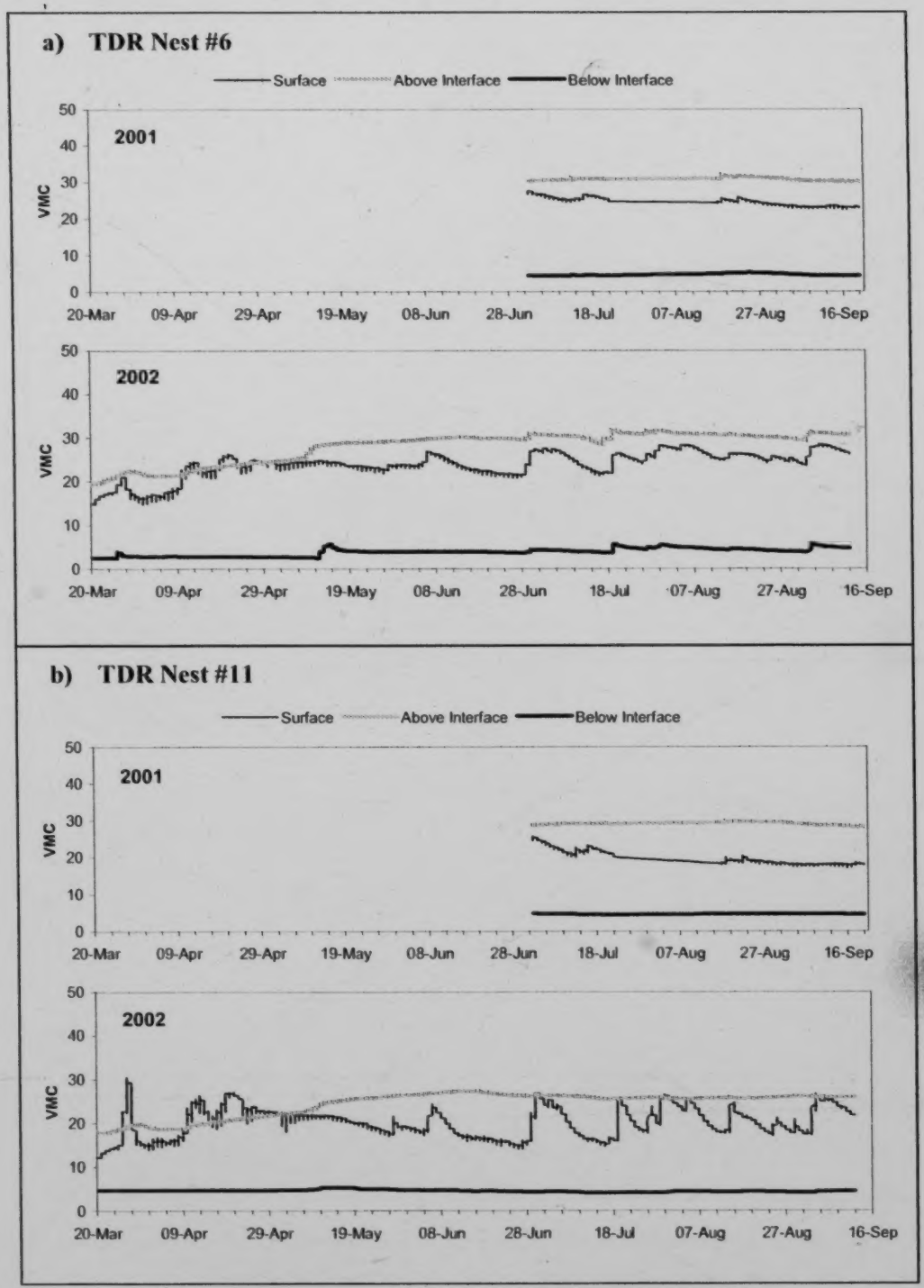

Figure 3.3 Volumetric moisture over time in 2001 and 2002 at two TDR nests
Note: No data from July 22 – August 16, 2001.

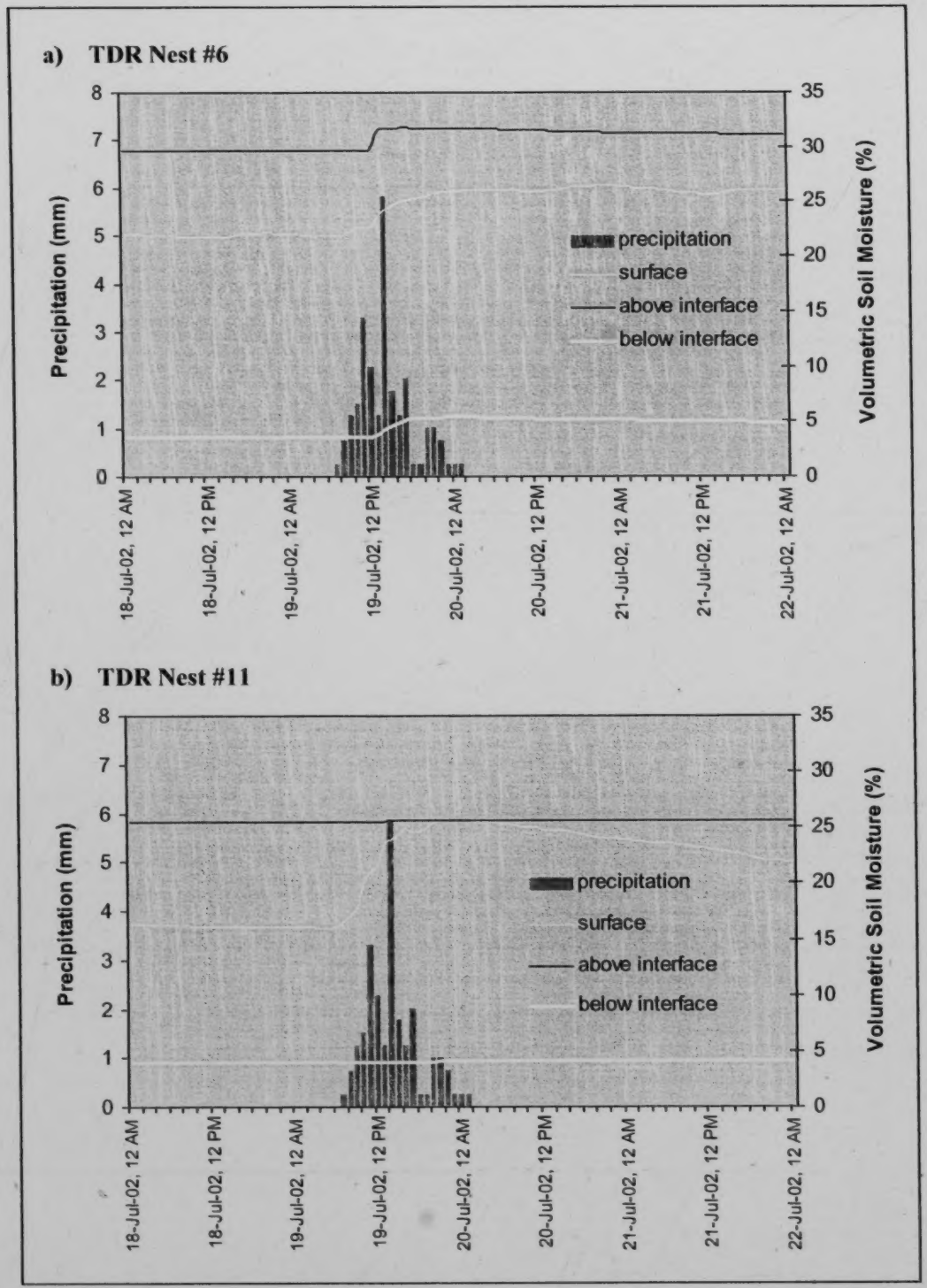

Figure 3.4 Precipitation and soil moisture at two TDR nests, July 18 – 21, 2002
Total precipitation over this period was 25.7 mm.

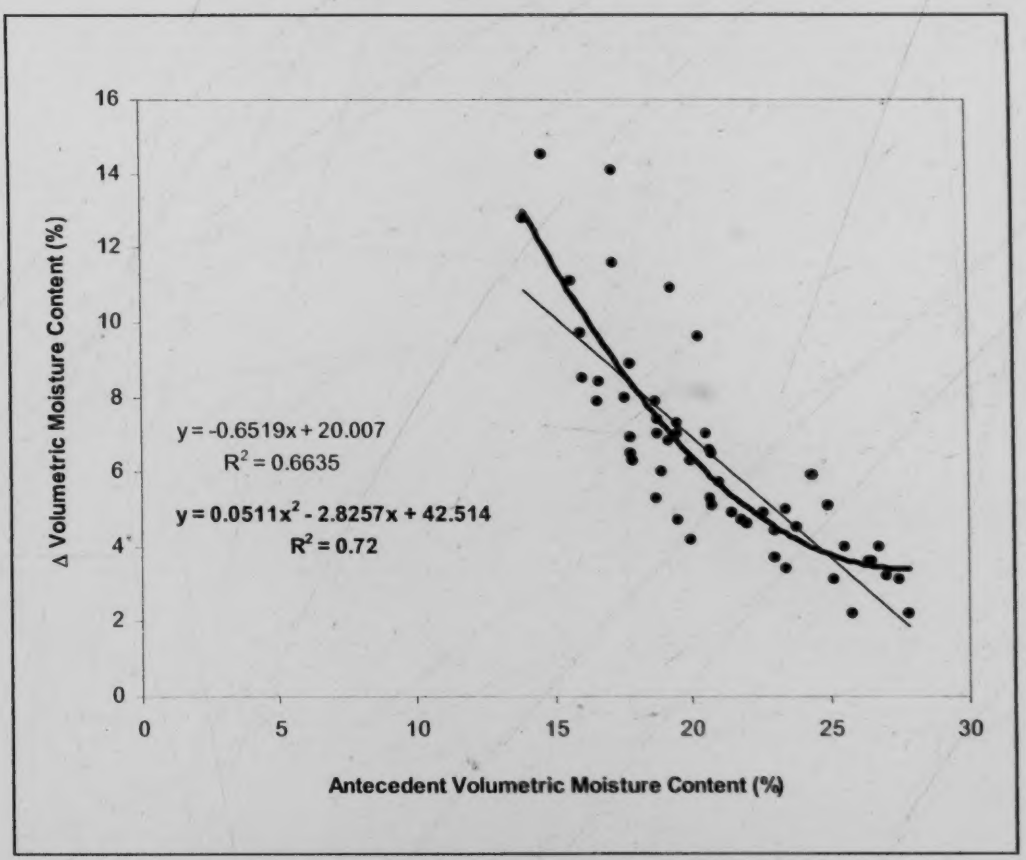

Figure 3.5 Relationship (linear, quadratic) between moisture gained at the surface and antecedent moisture conditions
Data from all surface probes, for all 5 precipitation events used.

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4.0 SOIL CHEMISTRY OF A TAILINGS SAND STORAGE FACILITY

The ultimate goal for a tailings sand structure, reclamation, could be threatened as salts from the process water are transported within the structure or reach the ground surface. The tailings (process) water has elevated concentrations of sodium, chloride and sulphate, while magnesium and calcium concentrations are reduced (MacKinnon and Doyle 1983). Table 4.1 gives a comparison of Syncrude's tailings water chemistry (from 1981) to natural groundwater in the area. With translocation, there is the potential for movement of these salts into the reclamation material (topsoil) and perhaps into the root zone. The main concern here is that root zone salinity/sodicity can adversely affect the revegetation of reclaimed areas, especially since most plants are more sensitive to salinity during germination than in later stages of growth (Richards 1954).

4.1 Introduction

4.1.1 Salinity and Vegetation

In general, salinity damage to vegetation is related to osmotic stress to the plant and/or a build-up of ions (chloride and sodium) in the leaf, which can cause growth or yield decline, leaf damage (cupping, yellowing, bronzing, necrosis, premature abscission and fall, whole twig dieback), increased leaf thickness and germination or enzyme impairment (Richards 1954, Robinson 1971).

Plant response to salinity varies greatly with plant species, as well as the overall plant condition, including the environmental conditions and other stresses the plant may be subjected to. Different species have different mechanisms for salt tolerance, but in general plant performance decreases as salt concentration increases (Table 4.2). Table 4.3 gives the relative salt tolerance of different plants (some of which can be found on the SWSS), with plants listed in order of decreasing salt tolerance. These data (taken from McKenzie (1988)) are based on field trials in Western Canada, with the EC categories representing the maximum salinity the crops will tolerate.

Sweetclover, which is one of the dominant species present on the instrumented watershed, are classified in Table 4.3 as having relatively high salt tolerance. Tree and shrub species found on the study site, which appear in Table 4.3, are aspen, white spruce, and dogwood, all of which are classified as having low salt tolerance. Several greenhouse studies have been carried out, using highly saline/sodic tailings waters (from composite tailings), to test the relative salt tolerance and suitability of northern boreal tree species for reclamation in the Athabasca oil sands. Renault et al. (1998) concluded that dogwood and hybrid poplar perform quite well under highly saline conditions (ECs of 3.0 – 6.7 dS m^{-1}), raspberry and strawberry seedlings were most susceptible to damage, and white spruce, black spruce and lodgepole pine showed only minimal effects. Khasa et al. (2002) found that the best performing seed lots, in response to treatments with tailings release water (EC of 6.2 dS m^{-1}), were red alder, trembling aspen, jack pine and lodgepole pine (in decreasing order of performance), but that different plant genotypes responded differently.

4.1.2 Soil Salinity/Sodicity Parameters

Several measures of salinity are used when describing the soil medium. The most direct are the concentrations of anions and cations (most usually chloride and sodium, salt constituents which often do not occur naturally). Salts in the root zone can make it difficult for vegetation to acquire water, as plants in this condition need to overcome the osmotic potential created by dissolved salts (Troeh and Thompson 1993). High concentrations of sodium in the soil can affect soil structure, causing clay dispersion and soil crust formation (Shainberg and Letey 1984). This in turn reduces the movement of air and water in the soil, affecting infiltration and hydraulic conductivity. Electrical conductivity (EC) is a measure of the ability of a medium to conduct electricity, and is related to the amount of ions present in solution; the more ions present, the less resistance to current flow, and the higher the electrical conductivity. In this respect, EC can be related to the soluble salt content in saturated soil extracts (Leskiw 1998). Higher EC values indicate a greater concentration of salts in solution, or a more saline soil (Table 4.2).

The Sodium Adsorption Ratio (SAR) is a measure of the relative amount of sodium in the soil (compared to other cations); it is the ratio of sodium to non-sodium cations in solution. The higher the SAR, the more sodium present, or the more sodic the soil is. As SAR increases above 12, the stability of soil aggregates decreases markedly (Leskiw 1998). Saturation percentage (percent saturation, or %Sat) is the amount of water required to saturate a unit of soil, and is closely related to sodicity in soils of loam or finer texture (Leskiw 1998). In highly sodic soils, clay dispersion occurs, and more water is required to saturate the soil. High saturation percentages may also occur in non-sodic soils (SAR of 4 or less) when the organic matter or clay content is high (Leskiw 1998). Table 4.4 outlines relative saturation percentage values for different soil textural classes. It is noted that %Sat for sands is generally higher than for other soils (in relation to the field-moisture range), because under saturated paste conditions, large pores of sand are filled with water, when under normal field conditions these would not retain water (Richards 1954). Table 4.5 gives the results of chemical analyses performed on soil samples from arid regions (Richards 1954), which included normal, saline, sodic, and saline-sodic soil samples. This table may be used as a rough guide for comparing expected cation, anion and salinity magnitudes in normal soils to saline/sodic soils.

4.1.3 Previous Assessment of Soil Chemistry on the SWSS

Over the period, 1997 – 2000, Syncrude Canada Ltd. contracted the Alberta Research Council to assess the status of soil and vegetation on the SWSS. Macyk (2000) collected soil, water and vegetation samples from a site just North of the current study site, to evaluate if water leaching out of the SWSS was having any negative impact on the growth of vegetation. Macyk (2000) found that ECs generally increased from 1997 – 2000 (more noticeably in the tailings sand), and SAR levels had increased (mainly in the lower depth of the soil cap and the tailings sand) over the three-year period. Although measured ECs at the site were all less than 3 dS m^{-1}, and SARs of greater than 10 were limited to the tailings sand, the increasing trend over 1997 – 2000 raised concern for the potential salinization of the topsoil in the future. These results prompted the current study.

4.2 Objectives

The global objective of this study was to determine if salinization was evident at the SWSS facility, and how it varied spatially and with depth. Along with salinity and sodicity, the relative magnitudes and spatial variation of cations, anions and pH, on the instrumented watershed were of interest. The research examined whether soil salinity would be an issue for reclamation/revegetation of the SWSS.

4.3 Materials and Methods

4.3.1 Soil Sampling

Soil sampling was undertaken on July 24, 2001 on the SWSS instrumented watershed. This was intended to give a 'snap-shot in time' representation of the soil chemistry, and specifically salinity/sodicity, on the site. Samples were collected by augering a hole 3 m to the left of each neutron access tube. Eight depths were sampled at each of the 52 locations, from the surface to a depth of 160 cm, at approximately 20-cm intervals (taken to the interface, not across it, so as to keep topsoil and tailings sand samples separate). The samples were then dried for several weeks, prior to analysis.

The 416 soil samples were submitted to Enviro-Test Laboratories, Edmonton, for analysis, and were tested for the 11 parameters outlined in Table 4.6. The soil chemistry data from these analyses were used to assess and quantify salinity conditions/patterns on the instrumented watershed. These results will then be used to link the salinity patterns with those of soil moisture (Section 5.0).

4.3.2 Statistical Analysis

A statistical analysis was applied to data for the 11 parameters outlined in Table 4.6 using the SAS statistical software. A split-plot design was chosen to describe the soil chemistry data, with replicate plot, tube and depth being the main sources of

variation. Instead of testing all 8 depths, and introducing repeated measures, three depth intervals were chosen for the statistical analysis: the surface (0 – 20 cm), near the interface (60 – 80 cm), and the deepest depth (140 – 160 cm). The following statistical model was used for the analysis:

$$Y_{ij} = \mu + \alpha_i + \tau_j + (\alpha\tau)_{ij} + \delta_k + (\tau\delta)_{jk} + \varepsilon_{ij}$$

where Y_{ij} = observed value (EC, SAR, %Sat, Cl, Na, Ca, Mg, NO_3, K, SO_4, pH)

μ = overall mean

α_i = effect of replicate plot(1, 2, 3, 4)

τ_j = effect of tube location (1, 2, 3, …, 13)

$(\alpha\tau)_{ij}$ = effect of interaction between replicate and tube

δ_k = effect of depth (20, 80, 160)

$(\tau\delta)_{jk}$ = effect of interaction between tube and depth

e_{ij} = experimental error (rep*tube*depth interaction)

A Tukey adjustment was used to test for significant difference among the four replicates, the 13 tube locations, and the three depth increments chosen. In all statistical analyses, a confidence level of 95% was chosen ($\alpha = 0.05$) to distinguish statistically significant variation.

4.4 Results and Discussion

4.4.1 Electrical Conductivity

Figure 4.1 shows EC values at all sampling locations, in the topsoil and at the lowest depth sampled. There was no strong spatial pattern in EC in the topsoil, as values were generally low (< 2 dS m^{-1}). The only EC value above 2 dS m^{-1} was at access tube location 4-9; there is uncertainty as to why this location stood out. In the tailings sand ECs were still quite low, ranging from 0.2 – 2.8 dS m^{-1} at the deepest point of measurement. From all sample locations and depths, no EC values were greater than 4 dS m^{-1} and there were only a few hot spots where the base of the topsoil had ECs of

2 – 3 dS m^{-1}. The average EC, over all locations and depths, was 1.0 dS m^{-1} (Table 4.7). Both replicate and tube location were statistically significant sources of variation in EC values (Table 4.7). The raw soil chemistry data are provided in the Appendix (Tables 6.9 – 6.19).

Three general trends for EC with depth were evident: (i) a strong peak in EC at the topsoil-tailings sand interface, (ii) a gradual increase in EC with depth, and (iii) a relatively uniform trend in EC with depth (Figure 4.2). The first two EC profiles were found in the wetter areas, whereas the drier areas took on a profile much like the third. ECs were highest at a depth of 60 – 80 cm (near the topsoil – tailings sand interface) and further down into the tailings sand. The greatest ECs were found at tube locations 4-1 (base), 4-5, 1-6, 4-6 (nearest the first waterway), and 4-9 with values of 2.4 – 3.3 dS m^{-1} at a depth of 60 – 80 cm (Table 6.9 in Appendix). Surface ECs were significantly lower than those at the interface or deeper in the tailings sand (Table 4.7).

4.4.2 Sodium Adsorption Ratio and Saturation Percentage

High sodicity was apparent in the tailings sand at a depth increment of 140 – 160 cm (i.e., SARs > 20) (Figure 4.3). In the topsoil (0 – 60 cm), SAR ranged from 0.3 – 23.1, with an average of 1.9 (Table 4.8). The higher SARs were found on the first bench (near the first waterway, tubes 4, 5, 6) and on uppermost slope (tube 13) near the second waterway (Table 4.7). It follows that the greatest sodicity is found in the wettest areas on site.

From the statistical analysis (Table 4.7), the average SAR value for the entire site was 5.9, replicate and tube location were both found to contribute significant variation to SAR, and the greatest sampling depth had significantly higher SAR values than did the surface or interface locations. SAR was generally low in the first 40 cm of topsoil (between 0.3 – 3.9), then increased with depth for tubes 1 – 6 (inclusive) and 13 (Table 6.10 in the Appendix). Figure 4.4 shows SAR with depth for select tube locations. Tubes 7 – 12 had consistent low SAR throughout the entire profile. The

highest SAR values were found at tube locations 5, 6 and 13, and at depths of 100 cm or deeper. Sodicity does not currently seem to be an issue in the root zone, as there were generally no SARs greater than 5 above a depth of 60 cm.

Percent saturation (%Sat) values varied greatly in the topsoil, but were quite uniform in the tailings sand (Table 4.8). Values in the topsoil ranged from 28 – 190 %, while values in the tailings sand ranged from 25 – 66 %. Percent saturations of greater than 100% may represent peat pockets in the topsoil. The statistical model was not significant for percent saturation, with neither replicate nor tube location contributing significant variation (Table 4.7). Complete saturation percentage data are given in the Appendix (Table 6.11).

4.4.3 Cation and Anion Concentrations

Chloride (Cl) and sodium (Na) concentrations were generally quite low (< 100 mg/L) at the surface and in the root zone, and tended to increase with depth. Figures 4.5 and 4.6 are contour plots of Cl and Na (respectively) in the root zone (40 – 60 cm) and in the tailings sand (140 – 160 cm). High Cl and Na concentrations were found in the tailings sand (below 80 cm), with sodium occurring in higher concentrations than chloride (Table 4.7). Hot spots on site were located around the first waterway (near access tube location 6) and above the second waterway (near access tube location 13) (Figures 4.5 and 4.6). The mean Cl and Na concentrations for the entire site were 83.5 mg/L and 136.1 mg/L, respectively, with both having extremely high variance (Table 4.7). Both replicate and tube location were identified as significant sources of variation in Cl and Na concentration, with tube locations 5, 6 and 13 (locations near waterways) having significantly higher Cl and Na concentrations.

The chloride ion acts as a tracer at this site, being that it does not occur naturally, but results from the added tailings slurry/process water. Chloride concentrations, as well as sodium, can be tied with soil moisture patterns, as the greatest Cl concentrations occur in the wetter areas (especially near the two waterways). The greatest Cl concentrations were found around the lower wetlands area (around access tube

location 6). The surface, interface and lowest depths sampled were each significantly different from the other in terms of Na and Cl concentration, with the highest concentrations occurring at depth and the lowest concentrations at the surface (Table 4.7). Figure 4.7 is a plot of Cl and Na with depth at select tube locations. At tube location 6, Cl and Na increased with depth while concentrations at tube 11 remained consistently low with depth. At tube location 3, the Cl and Na concentration peaked at the interface, but stayed fairly low into the tailings sand. Complete Cl and Na data are included in the Appendix (Tables 6.12 and 6.13).

After a vibracore geochemical survey on the instrumented watershed, completed by other researchers, it was noted that sodium appears to move into the capillary fringe more effectively than chloride, causing SARs to increase before conductivities do (Qualizza Personal Communication). The opposite was found in the current study; SARs tended to decrease consistently throughout the profile, while conductivity peaks at the approximate topsoil-tailings sand interface in most tubes.

Calcium (Ca) and magnesium (Mg) concentrations had similar patterns to each other with depth, peaking at the topsoil-tailings sand interface (Figure 4.8). Interestingly, the peaks in Ca and Mg concentration at tube 3 were larger in comparison to others locations (however they were not significantly different from concentrations at other tube locations, Table 4.7). This may be a result of interface depth (Table 6.6 in Appendix), since of the three tubes showcased in Figure 4.8, tube 3 has the deepest interface (average of 72 cm), followed by tube 6 (average of 68 cm), and tube 11 has the shallowest interface (average of 50 cm). The high concentrations at tube location 3 were also evident for EC, K and SO_4 (Tables 6.9, 6.17 and 6.18).

For both Ca and Mg, neither replicate nor tube location contributed significant variation to the concentration measured. Ca was much more abundant on average (79.9 mg/L average for entire site) than Mg was (21.2 mg/L average for entire site). For the three depths analyzed, each was significantly different from the other, with the greatest Ca and Mg concentrations found at the interface and the lowest

concentrations at depth in the tailings sand (Table 4.7). Average concentrations at depth, however, were greater than those generally found in the tailings process water (Table 4.1). The main source for Ca and Mg at this site is likely the topsoil, with the high concentrations near the interface likely being a result of their downward translocation in solution. Complete Ca and Mg data are given in the Appendix (Tables 6.14 and 6.15).

Values for available nitrogen (in the form of nitrate, NO_3) ranged from 0.4 to 7.9 mg/kg. These concentrations indicate an overall deficiency in plant available nitrogen for the root zone (0 – 60 cm) for agronomic crops, according to the available plant nutrient limits given by Fageria et al. (1997). The low concentrations of NO_3 in the soil suggest that immobilization of nitrogen is occurring, which would make it difficult for plants to sequester nitrogen. Nitrogen in the soil normally occurs in this form, NO_3, and generally converts to this form relatively rapidly (Mapfumo Personal Communication). For nitrate, the four replicate plots introduced significant variation, but tube location did not (Table 4.7). Nitrate levels in replicate 4 were significantly higher than those in the other replicates, and nitrate levels in replicate 2 were significantly lower than those in the other replicates. As would be expected, nitrate concentrations were highest in the topsoil, and lowest in the tailings sand (Table 4.7). Complete NO_3 data are given in the Appendix (Table 6.16).

In terms of available plant nutrients, potassium (K) levels also fell within the category of deficient (according to Fageria et al. (1997)), having ranged from 1 – 18 mg/L in the topsoil (Table 4.9). For K, the four replicates introduced significant variation, but tube location did not (Table 4.7). Potassium was significantly higher at the greatest depth measured than at the interface or surface. Complete K data are provided in the Appendix (Table 6.17). Sulphate (SO_4^{2-}) concentrations ranged from 14 – 1430 mg/L in the topsoil and 10 – 2420 mg/L in the tailings sand (Table 4.9), and were greatest at the topsoil-tailings sand interface (Table 4.7), just as calcium and magnesium were. Neither replicate nor tube location introduced significant variation for SO_4 values, but variance in SO_4 was very high (Table 4.7). High SO_4 concentrations are expected in

the tailings sand, being that the process water is high in SO_4 (Table 4.1). Complete SO_4 data are provided in the Appendix (Table 6.18).

4.4.4 pH

Values for pH were comparable among the 13 sampling locations from the bottom to the top of the site (coefficient of variation 7.7 %, Table 4.7). In the topsoil, pH values ranged from 5.4 – 8.5 (Table 4.10). Into the tailings sand, pH values increased, ranging from 6.6 – 9.5. Neither replicate nor tube location introduced significant variation in pH values, however, tubes 4, 5, 6 and 13 (tubes in the wetter areas) had slightly higher, or more basic, pH values (Table 4.7). Values in the tailings sand were significantly higher (more basic) than pH at the interface or at the surface. Complete pH data are given in the Appendix (Table 6.19).

4.5 Conclusions

The root zone of the instrumented watershed is not currently showing signs of elevated salinity. Salinity and sodicity are apparent, sodicity more so, but it is generally confined to the tailings sand (i.e., below a depth of 80 cm). Salinity and sodicity vary with soil moisture, with the more saline and sodic conditions found in the wetter areas (near tubes 5, 6 and 13). The wetland area on the first bench (tubes 6) may be a concern for the future, as surface chloride concentrations and electrical conductivities (ECs) are highest here. Overall, only approximately 30 % (or less) of the instrumented watershed is affected by salinity/sodicity, and this is in the tailings sand.

Nitrogen and potassium were deficient in the topsoil (0 – 60 cm), according to agronomic guidelines.

Table 4.1 Major ion chemistry of Syncrude tailings water and natural groundwaters (ppm*)

Taken from MacKinnon and Doyle (1983).

	Na	K	Mg	Ca	Cl	SO_4	HCO_3
Tailings Water	14	0.30	0.30	0.30	2.70	4.20	8.80
Natural Groundwater	0.09	0.03	1.05	2.18	0.04	0.07	3.47

*For purpose of comparison to the current study, the above concentrations in ppm are assumed to be equivalent to mg/L (considering the relatively dilute solutions).

Table 4.2 Scale of electrical conductivity (EC)

EC (dS m^{-1})	0	2	4	8	16
General soil response	normal soil low salinity	intermediate salinity	saline soil		
Plant response*	salinity effects mostly negligible	very sensitive crops may be restricted	yields of many crops restricted	only tolerant crops yield satisfactorily	

*from Richards (1954)

Table 4.3 Relative tolerance of various plants to salinity*
Adapted from McKenzie (1988).

Tolerance/ EC (dS m^{-1})	Field crops	Forages	Vegetables and fruits	Trees, shrubs and ornamentals
		Beardless wildrye		
		Puccinellia distans		
		Levonns alkaligrass		
High 16		Alkaki sucatan		
		Altai wildrye		
	Kochia	Tall wheatgrass		Siberian salt tree
	Sugar beets	Russian wildrye		Sea buckthorn
		Slender wheatgrass		Silver buffaloberry
8	6-row barley	Birdsfoot trefoil		Hawthorn
	Safflower			Russian olive
	Sunflower	Sweetclover	Asparagus	
	2-row barley	Alfalfa	Garden beets	American elm
	Fall rye		Spinach	Siberian elm
	Winter wheat	Bromegrass	Zucchini	Villosa lilac
	Spring wheat	Crested wheatgrass		Laurel leaf willow
Moderate	Oats	Intermediate wheatgrass	Tomatoes	Spreading juniper
	Yellow mustard	Meadow fescue	Broccoli	Poplar
		Reed canarygrass	Cabbage	Ponderosa pine
	Flax			
	Canola		Apple	Mountain ash
4			Cucumber	Common lilac
				Siberian crab apple
	Corn		Sweet corn	Manitoba maple
			Potatoes	
Low		Timothy		Colorado blue spruce
		White dutch clover	Carrots	Rose
		Redtop	Peas	Viburnum
	Peas	Alsike clover	Onions	Douglas fir
	Field Beans	Red clover	Strawberry	Balsam fir
			Beans	Cottonwood
			Raspberry	Aspen
				White Spruce
				Birch
				Cotoneaster
				Black walnut
				Dogwood
0				Little-leaved linden

* Maximum salinity crops will tolerate when combined with intermittent moisture stress throughout growing season, based on field trials in Western Canada and on relative tolerances obtained from lysymeter experiments or other closely manage experiments (McKenzie 1988).

Table 4.4 Saturation percentage as influenced by soil texture
Taken from Richards (1954).

Soil Group	%Sat		
	min	*max*	*ave*
coarse	16.0	43.1	31.8
medium	26.4	60.0	42.5
fine	41.8	78.5	59.5
organic	81.0	255	142

Table 4.5 Chemical analyses of soil samples from arid regions (saturation extract determinations)
Adapted from Richards (1954)*.

Soil Samples^	EC (dS/m)	Cations (mg/L)				Anions (mg/L)		SAR
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SO_4^{2-}	Cl^{-}	
Normal								
soils 2741	0.6	54	27	28	36	100	31	0.8
2744	1.7	67	24	280	27	206	175	7.5
R-2867	0.8	55	21	120	7	128	16	3.5
Saline								
soils 574	13.9	631	452	2345	8	4323	2765	17.4
756	12.0	741	413	1816	16	2987	1666	13.3
575	8.8	569	277	1218	43	3554	1028	10.5
Sodic								
soils 2747	1.7	22	17	359	16	407	101	13.9
2738	2.5	28	12	494	11	183	592	19.6
535	3.2	22	4	671	160	221	266	35.0
Saline-sodic								
soils 2739	9.2	135	120	1828	19	965	2553	27.6
2740	16.7	649	465	3334	20	5043	3723	24.4
536	5.6	12	11	1345	63	1033	578	67.6

* Ion concentrations were converted from meq/L to mg/L using each ions respective atomic weight and valence (and rounded to the nearest whole number).
^ Soil samples numbers as per Richards (1954).

Table 4.6 Soil chemistry analysis parameters

Saturated Paste, pH and EC		**SAR and Cations in sat. soil**	
% saturation	(%)	Calcium (Ca)	(mg/L)
pH in saturated paste	(pH)	Potassium (K)	(mg/L)
conductivity of saturated paste	(dS m^{-1})	Magnesium (Mg)	(mg/L)
		Sodium (Na)	(mg/L)
		SAR	(-)
Chloride and Sulphate in sat. soil		Available Nitrate - N	(mg/kg)
Chloride (Cl)	(mg/L)		
Sulphate (SO_4)	(mg/L)		

Table 4.7 Statistical analysis of soil chemical properties
All locations, for depths 0 – 20 cm, 60 – 80 cm and 140 – 160 cm.
✓ = statistically significant variation ($\alpha = 0.05$).

Test	EC (dS/m)	SAR	%Sat	Cl (mg/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	NO_3 (mg/kg)	K (mg/L)	SO_4 (mg/L)	pH
mean	1.0	5.9	44.1	83.5	136.1	79.7	21.2	1.5	5.1	236.1	7.7
variance	0.56	116.2	1194	17406	27919	9732	498.8	0.72	10.4	111244	0.35
stddev	0.75	10.8	34.5	131.9	167.1	98.7	22.3	0.9	3.2	333.5	0.59
coef. Var	75.3	183.7	78.4	157.9	122.8	123.7	105.5	56.8	63.9	141.3	7.7
stderr	0.06	0.86	2.8	10.6	13.4	7.9	1.8	0.07	0.26	26.7	0.05
Model	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
R^2	0.843	0.853	0.561	0.908	0.877	0.778	0.783	0.715	0.680	0.788	0.840
rep	✓	✓		✓	✓			✓	✓		
tube	✓	✓		✓	✓						
LSMeans	4 1.3	1 8	3 54	4 106	4 186	4 99	4 25	4 2	4 6	4 345	1 8
↑ (rep)	1 1.0	4 7.1	4 41	1 98	1 149	2 87	2 25	1 1	2 5	2 216	3 8
	3 0.9	3 5.1	2 40	3 78	3 121	1 67	3 18	3 1	1 5	1 200	2 8
	2 0.8	2 3.2	1 40	2 52	2 88	3 66	1 17	2 1	3 4	3 183	4 8
Contrasts											
rep 1 vs 2		✓						✓			
1 vs 3											
1 vs 4								✓			
2 vs 3								✓			
2 vs 4	✓			✓	✓			✓			
3 vs 4					✓			✓	✓		
LSMeans	6 1.8	6 16.9	5 65	6 277	6 329	3 166	3 44	6 2.1	3 7.3	3 522	5 8.0
(tube)	5 1.5	5 12.7	2 58	5 194	5 284	9 134	9 31	13 1.8	9 6.2	9 397	4 8.0
	3 1.3	4 9.9	1 48	13 179	13 200	1 110	1 28	12 1.6	6 5.9	1 352	6 7.9
↑ moisture	1 1.3	13 9.8	3 48	4 104	2 171	8 100	2 26	5 1.6	8 5.9	2 289	13 7.9
	13 1.2	2 6.7	6 47	1 96.5	1 168	6 83	8 21	10 1.6	5 5.2	6 283	7 7.7
	2 1.2	1 6.7	10 42	2 94.5	4 162	2 83	6 20	9 1.5	10 5.2	5 271	12 7.7
	4 1.0	3 4.1	13 41	3 52.6	3 136	5 59	10 18	8 1.5	7 5.0	8 258	8 7.6
	9 0.9	7 2.8	7 40	12 35.7	7 81	10 55	11 16	2 1.4	1 4.8	13 175	11 7.6
	8 0.8	12 2.0	8 40	7 18.3	9 73	7 54	5 15	11 1.4	4 4.7	4 153	3 7.6
	7 0.7	8 1.7	4 39	8 10.2	8 63	4 53	12 15	1 1.3	2 4.6	7 148	9 7.6
	12 0.5	9 1.5	9 36	10 9.0	12 51	11 47	4 14	3 1.2	11 3.8	10 86	1 7.6
	10 0.5	10 0.8	12 35	9 8.5	10 28	13 47	7 14	4 1.2	12 3.7	11 69	2 7.6
	11 0.4	11 0.8	11 34	11 6.7	11 23	12 45	13 13	7 1.2	13 3.7	12 67	10 7.5
Signif. Contrasts	1 vs 11 3 vs 11 5 vs 10-12 6 vs 7-12	1 vs 6 2 vs 6 3 vs 6 5 vs 7-12 6 vs 7-12	none	1 vs 6 2 vs 6 3 vs 5,6,13 4 vs 6 5 vs 7-12 6 vs 7-12 7 vs 13 13 vs 8-12	1 vs 6 2 vs 6 3 vs 6 4 vs 6 5 vs 7-12 6 vs 7-12 10 vs 13 11 vs 13	none	none	none	none	none	none
LSMeans	80 1.2	160 13	80 56	160 152	160 225	80 127	80 31	20 1.7	160 6.3	80 397	160 8.2
↑ (depth)	160 1.2	80 3	20 47	80 74	80 134	20 81	20 21	80 1.6	20 4.6	160 193	20 7.5
	20 0.6	20 1.3	160 30	20 24	20 50	160 32	160 12	160 1.2	80 4.3	20 119	80 7.4
Contrasts											
20 vs 80	✓			✓	✓	✓	✓			✓	
20 vs 160	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
80 vs 160		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 4.8 Comparison of sodicity and %Sat in topsoil and tailings sand

	SAR		%Sat	
	topsoil	*tailings*	*topsoil*	*tailings*
Mean	1.9	8.4	51.0	30.2
Min	0.30	0.20	28.0	25.0
Max	23.1	69.7	190.0	66.0
Stdev	2.0	11.8	24.5	4.3
CV (%)	109	140	48	14

Topsoil is taken to be 0 – 60 cm, tailings sand is taken to be 80 – 160 cm.

Table 4.9 Comparison of NO_3, SO_4 and K in topsoil and tailings sand

	NO_3 (mg/kg)		K (mg/L)		SO_4 (mg/L)	
	topsoil	*tailings*	*topsoil*	*tailings*	*topsoil*	*tailings*
Mean	1.6	1.2	3.9	5.9	227.2	197.4
Min	0.4	0.4	1.0	2.0	14.0	10.0
Max	7.9	4.4	18.0	33.0	1430.0	2420.0
Stdev	1.1	0.6	2.6	3.7	264.6	285.5
CV (%)	65	48	65	63	116	145

Topsoil is taken to be 0 – 60 cm, tailings sand is taken to be 80 – 160 cm.

Table 4.10 Comparison of pH in topsoil and tailings sand

	pH	
	topsoil	*tailings*
Mean	7.4	8.0
Min	5.4	6.6
Max	8.5	9.5
Stdev	0.4	0.5
CV (%)	5	7

Topsoil is taken to be 0 – 60 cm, tailings sand is taken to be 80 – 160 cm.

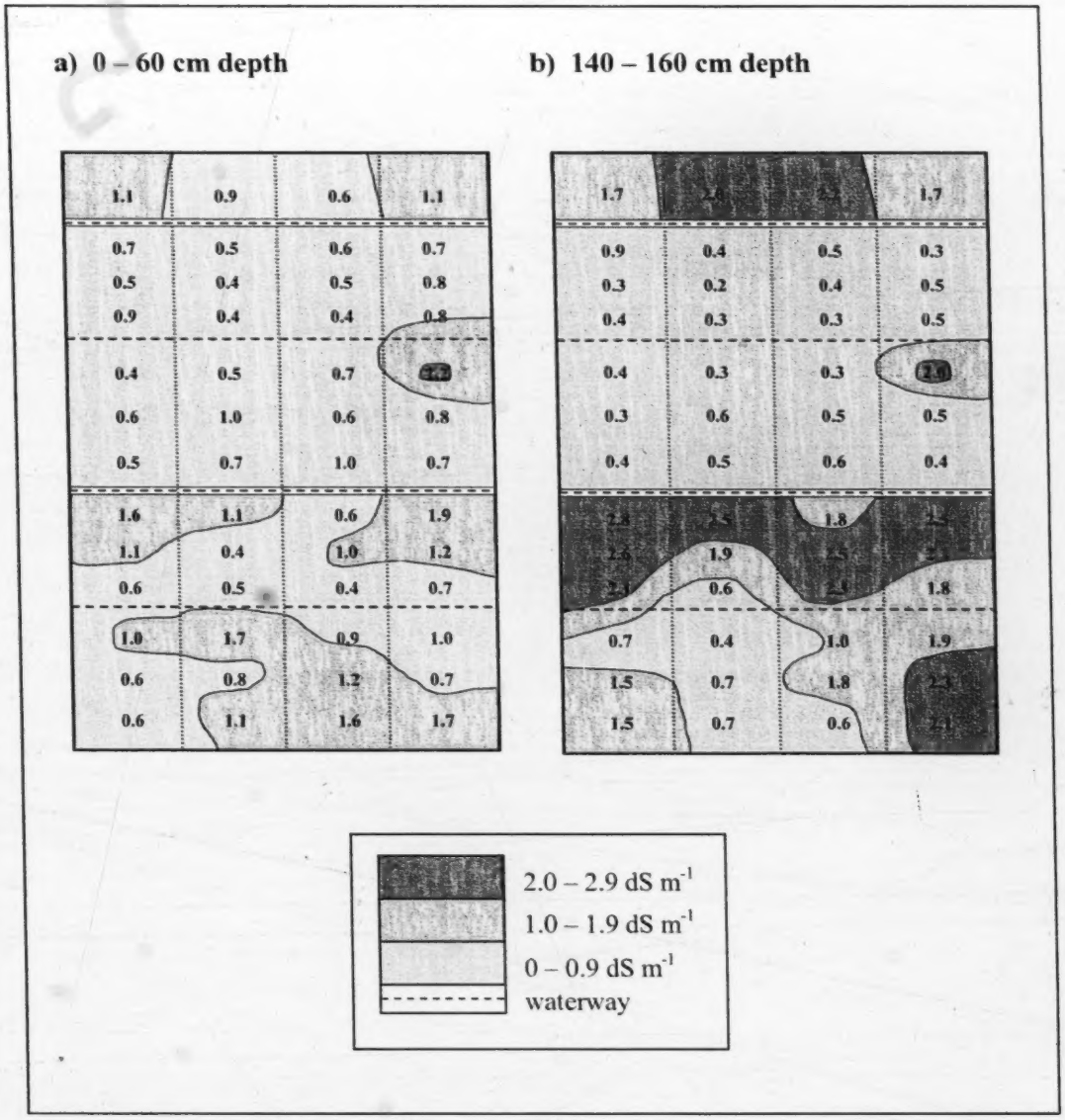

Figure 4.1 Contour plots of EC (dS m^{-1})

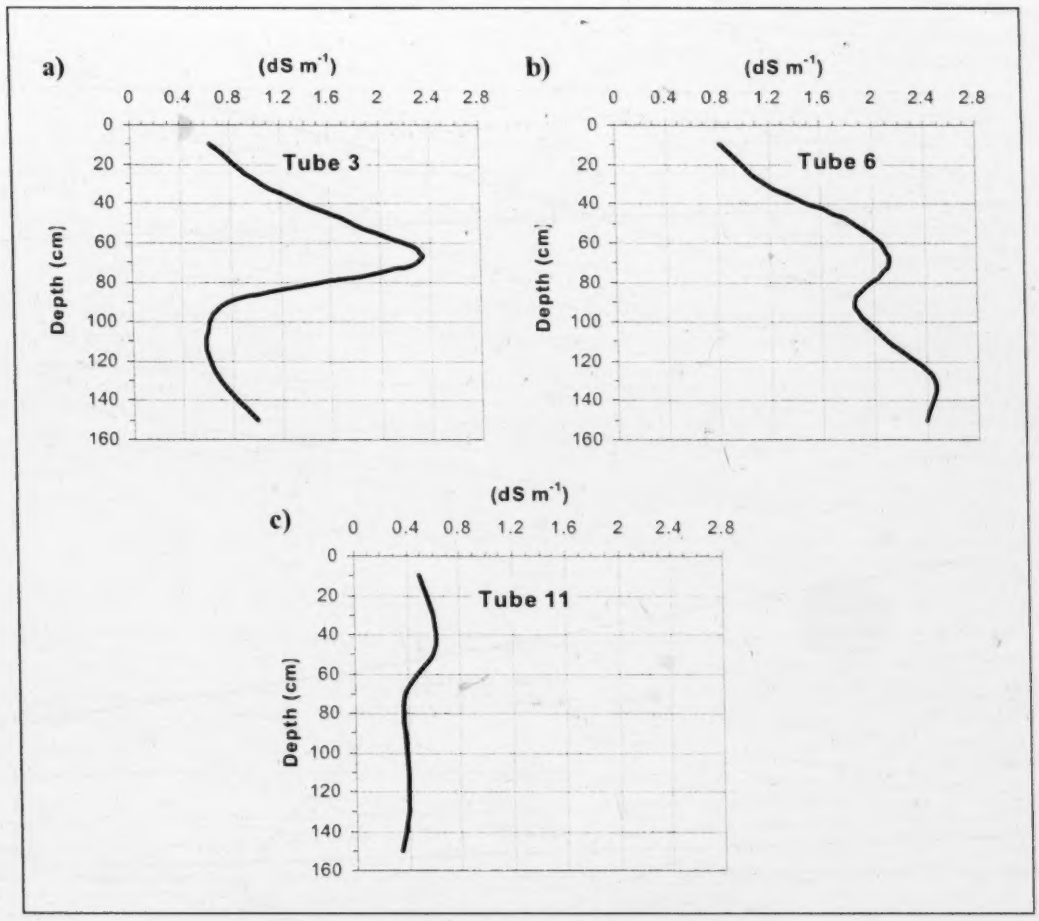

Figure 4.2 Profiles of EC with depth at tubes 3, 6 and 11
a) area of intermediate soil moisture b) wettest area c) driest area
Data averaged across four replicates.

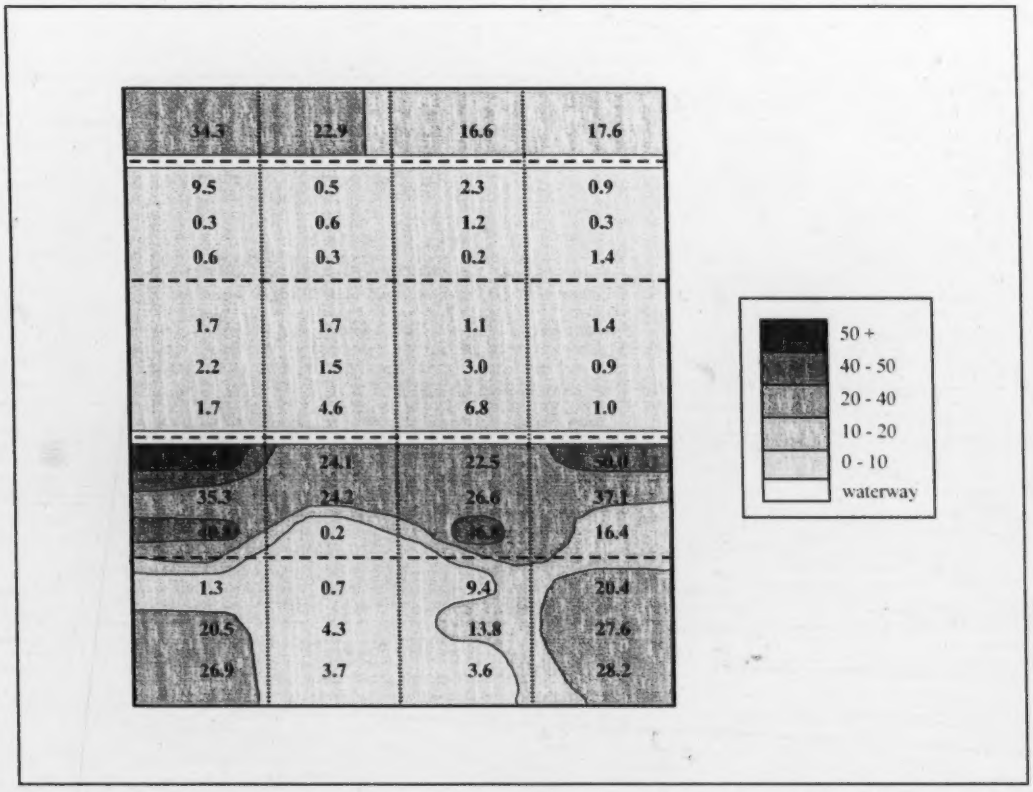

Figure 4.3 Contour plot of SAR for depth increment of 140 – 160 cm

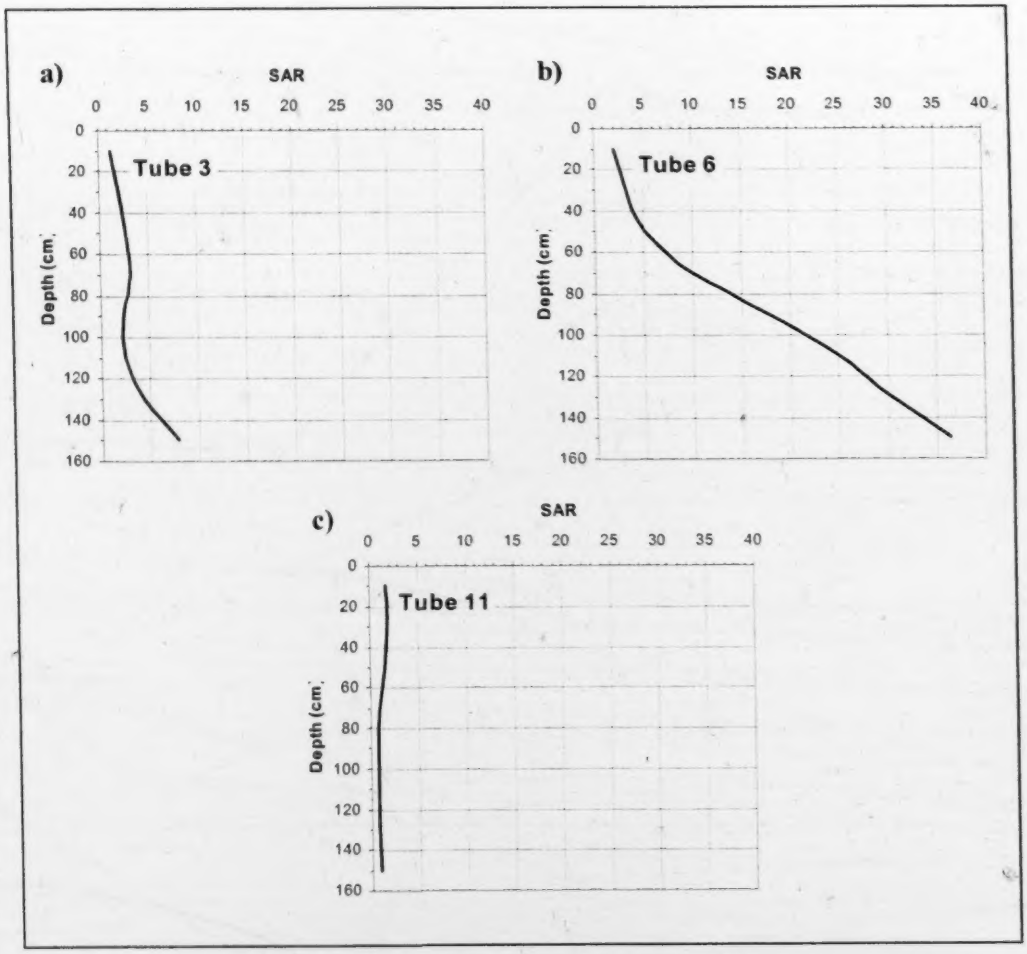

Figure 4.4 SAR with depth at tubes 3, 6 and 11 (averaged across replicates)
a) area of intermediate soil moisture b) wettest area c) driest area

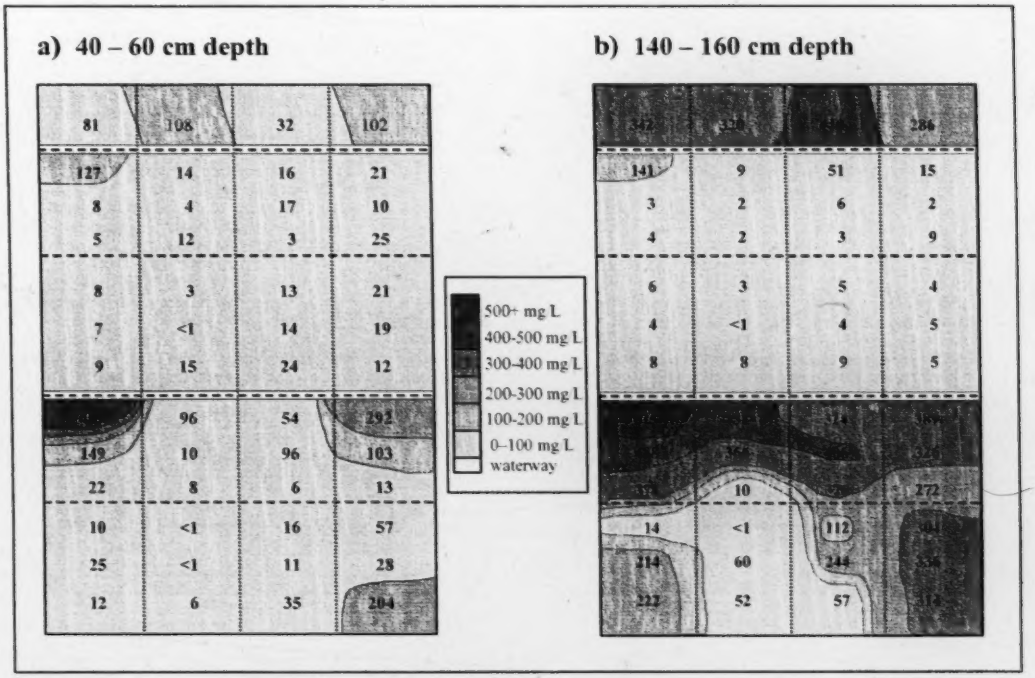

Figure 4.5 Contour plots of chloride concentration (mg/L)

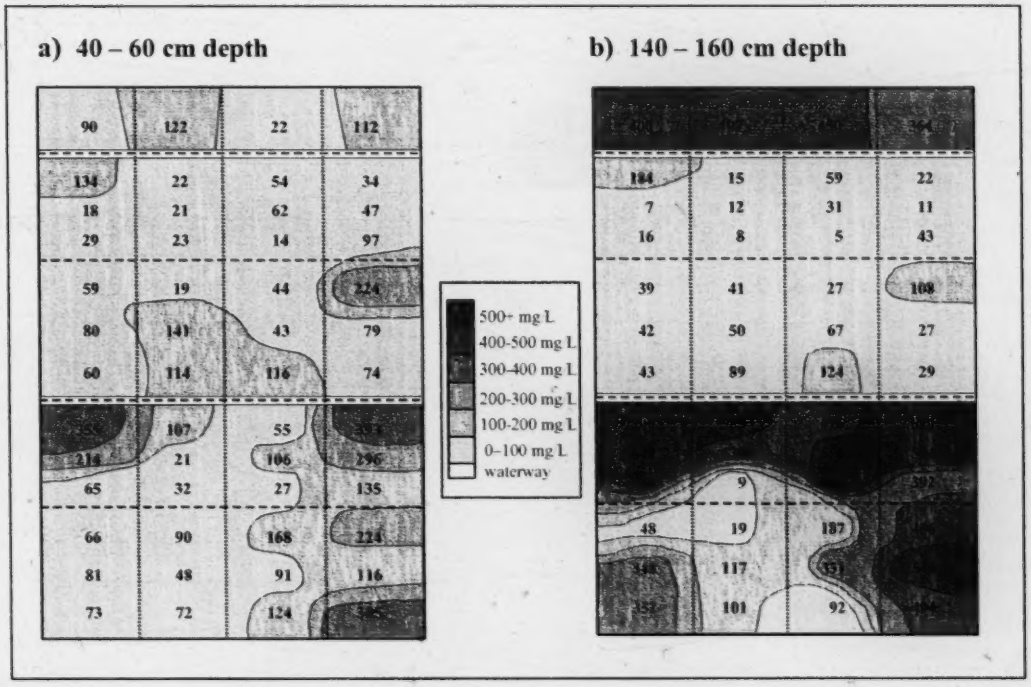

Figure 4.6 Contour plots of sodium concentration (mg/L)

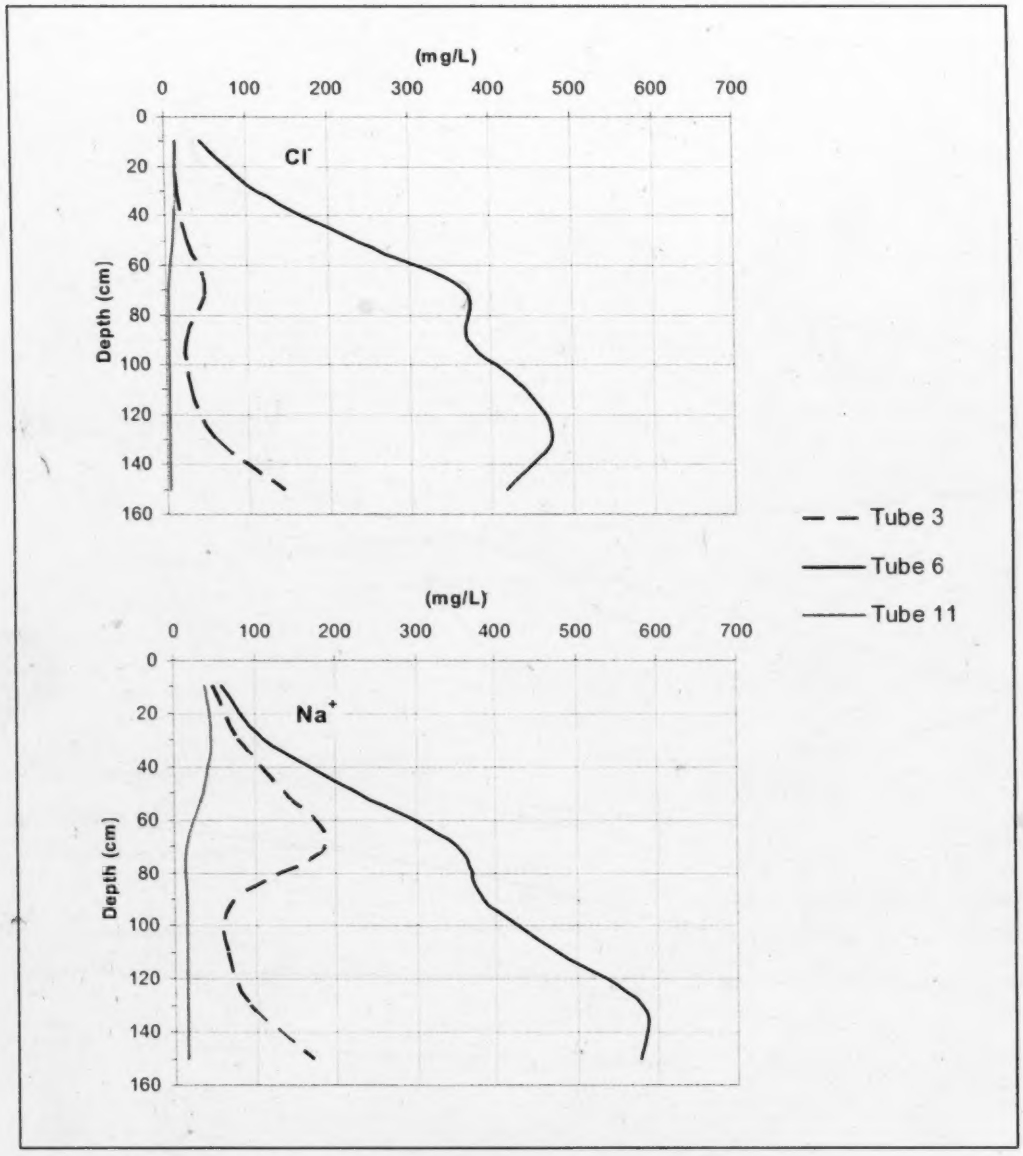

Figure 4.7 Chloride and sodium concentration with depth

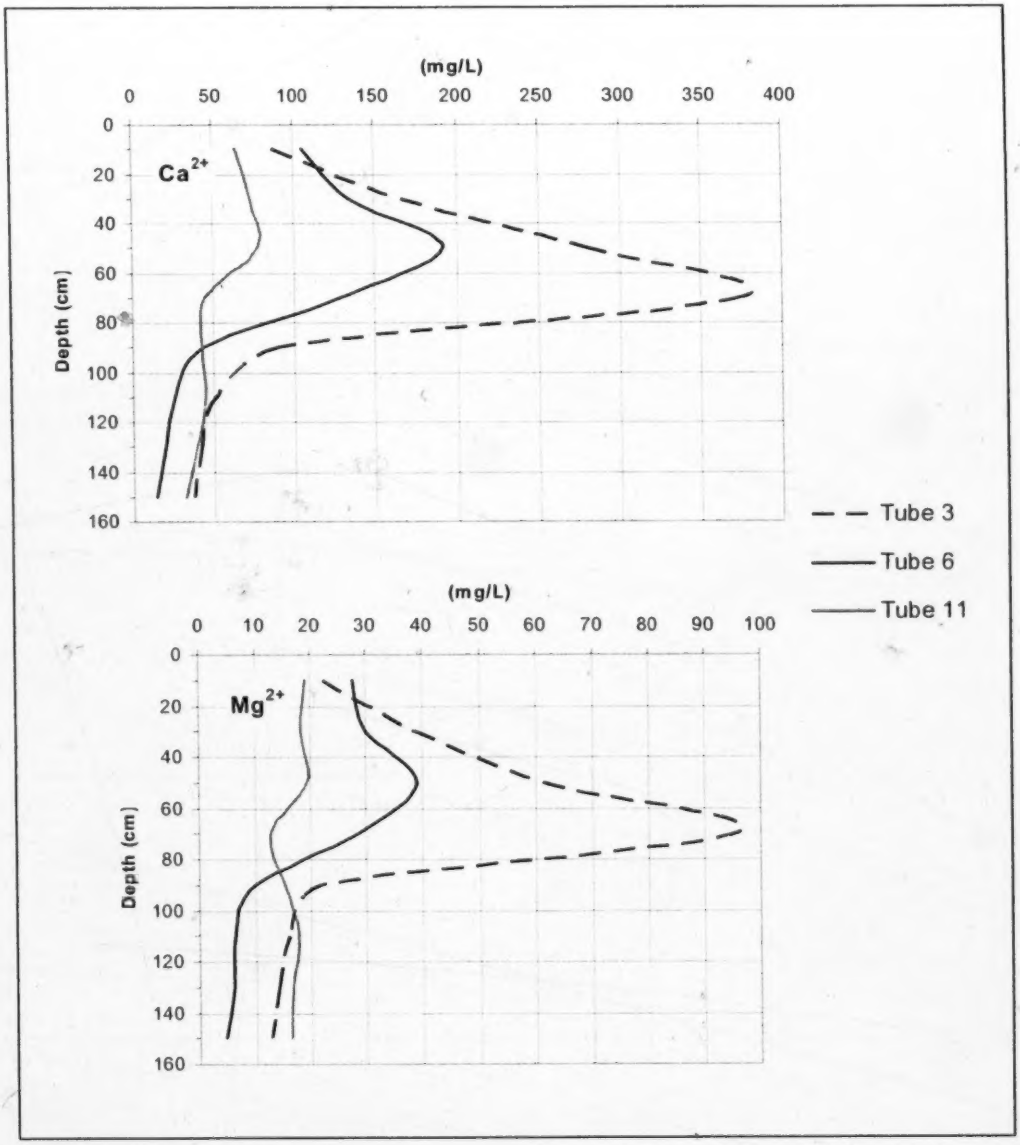

Figure 4.8 Calcium and magnesium concentration with depth

4.6 References

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5.0 SYNTHESIS

The ultimate goal for reclamation of the SWSS is a stable, self-sustaining forested ecosystem. In order for this goal to be met, the soil (its moisture and chemical regime) must provide a hospitable, non-limiting environment for vegetation, as well as fauna, and discharges from it must not detrimentally affect the surrounding environment.

5.1 Soil Moisture and Salinity

On the instrumented watershed of the SWSS, trends in salinity and soil moisture coincided; the wetter areas (top of study site, first backslope near wetlands area, and base of structure) were also areas of higher salinity/sodicity. Since chloride can be used as a tracer on this site, these wetter areas may indicate seepage points or discharge areas, as process water is diluted along its flow within the structure. If this is the case, the flow system could continue to bring saline waters into these areas, from the top and deeper within the structure. However, salinity and sodicity were generally confined to greater depths in the tailings sand, which may suggest that the system is flushing and slowly removing the salts from the profile. Figure 6.3 (in the Appendix) compares the major soil parameters studied (degree of saturation, bulk density, electrical conductivity, and topsoil depth) among each neutron access tube location.

Given the soil moisture and salinity results of this study, there may several possible flow scenarios for the instrumented watershed: i) the area near the top of the site (slope E) is likely receiving water from the top of the structure, where the tailings slurry is applied, ii) slope B is likely receiving water from the adjacent wetlands area, and/or iii) the wetter areas at the top, mid and base of the site may all be receiving water from the top of the structure. These scenarios represent both localized and intermediate/regional flow systems, and either (or both) of these systems could be

operating at this site. If the tailings sands are in fact hydrophobic at slope D, this area may be re-routing water, causing flow to remain deeper beneath this area.

On the instrumented watershed, neither waterlogging nor salinity was an issue in the topsoil. However, it is uncertain as to what conditions will be like in future years; this will likely be a function of many variables, with the important ones being the meteorological conditions and groundwater flow. Soil moisture at depth, well into the tailings sand, did not change markedly over the study period, which is a promising result. It will be interesting to follow the moisture dynamics on this site into the future when tailings slurry ceases to be added to the top of the structure, and flow within the structure equilibrates. The low salinity in the topsoil and near the interface is reassuring, suggesting that salts are not currently being translocated upward from the tailings sand and/or else there is sufficient downward percolation of water to keep the salts at depth. Just as the textural discontinuity was shown to limit water movement across the interface, from the topsoil to the tailings sand, it will also likely provide a barrier to upward moisture and solute movement.

In terms of vegetation stability on site, the topsoil appears to be hospitable, holding adequate moisture and having low salinity. The only potential for concern would be for more sensitive species on the first backslope (near access tube location 6), where ECs approach 3 dS m^{-1} near the interface and SARs approach 10 (Tables 6.9 and 6.10 in the Appendix). The tailings sand was quite dry in most areas, which is likely a result of the textural discontinuity restricting downward flow across the interface, but could also be a result of hydrophobic conditions. Nitrate and potassium levels were low on the instrumented watershed, therefore, vegetation stability may be more influenced by nutrient status than by salinity or moisture conditions.

5.2 Applications to Reclamation in the Oil Sands

Salinity and moisture contents were not high in the root zone, which alleviates prior concerns regarding the impact to revegetation of the SWSS. The explanation for these findings most likely lies in the added topsoil (reclamation material). The 60 –

80 cm of clay loam topsoil that was added to the instrumented watershed provides a good medium for vegetation, as it holds moisture well. With less topsoil, less overall moisture is held, which would possibly cause deeper rooted plant to search for moisture into the tailings sand. The direct placement of topsoil over tailings sand, creating a textural discontinuity, promotes fluid retention in the topsoil and drier conditions just below the interface in the tailings sand. This textural discontinuity in turn restricts the upward movement of moisture and salts into the topsoil.

If the tailings sand is hydrophobic in areas, this could be troublesome if the root systems of plants/trees extend below the topsoil-tailings sand interface in search of water. However, there could be an advantage to the dry conditions of the tailings sand: if the tailings sands are in fact hydrophobic, they would provide a barrier to the upward movement of saline process water. The question is whether or not having dry conditions in the tailings sand is desirable. If not, exposed tailings sand, following application to a tailings facility, should not be left to dry out before topsoil is added.

The two waterways (lateral berm channels) on the instrumented watershed were designed to divert surface water and seepage off the structure. The upper waterway (on the second backslope) appears to accomplish this; water moves along a narrow channel. However, the first waterway (on the first backslope) is more of a wetland area; it is quite large and does not appear to flow (it holds standing water). Peat was added to these channels and is likely causing greater water retention here, slowing or preventing the flow of water. The question, again, is whether or not this is desirable. Incorporating wetlands areas would increase the site diversity, although the peat in these areas could also act as a wick, bringing salts into these areas.

The conditions at this site were rather dry prior to and during the study, therefore it will be interesting to see how the soil moisture and soil chemistry respond to increased precipitation. One question could be: Would the results of this study apply during a wetter or 'normal' year? At this site it appeared that vegetation was taking up most of the moisture, therefore, it is not anticipated that moisture conditions would

change much (especially in the tailings sand) with increased precipitation (except that the evaporative demand (and moisture needs of the vegetation) might be better met). In terms of salinity, this site has probably had somewhat of a worst case scenario, being that salinization is normally more of an issue during drier periods.

5.3 Further Research

This research was the first of this nature and scale on the SWSS, or any other tailings structure of this kind. Research will continue on this structure into the future. Now that the general soil moisture regime and near surface salinity has been characterized, a more detailed investigation of the instrumented watershed can ensue.

Although this study has somewhat alleviated the initial concerns of high water tables and saline soil conditions, to assess the status and success of reclamation on the SWSS, reclamation specialists and environmental planners also need to know:

i. What are the patterns of water flow within the instrumented watershed? Within the entire SWSS structure?
ii. How do patterns in plant species (and their condition) compare to soil moisture/salinity patterns?
iii. Could salinization or waterlogging potentially affect soil quality and vegetation in the future?
iv. Can this structure sustain a forested ecosystem?

Neutron probe measurements should continue on the instrumented watershed (to observe the change in soil moisture over time, and as meteorological conditions change). More access tubes could be added, on slope E and further up towards the beach, closer to the waterways, and possibly closer to the toe ditch. Since the four plots were statistically significant replicates, neutron probe measurements could be reduced to three plots (keeping replicates 1 and 4, those with the least and most topsoil (respectively) and either of the other two replicates).

If soil moisture measurement surrounding the topsoil-tailings sand interface is to continue, it would be useful to move the TDR station upslope, to the second backslope (near access tubes 7 – 12). This area is the driest on site, and it would be interesting to compare the moisture dynamics at the interface there to those that were studied further down, in the wetter area. Also in the dry area, an investigation into the hydrophobicity of tailings sand should be carried out to determine if these areas could ever be wetted.

It would be important to repeat the soil sampling on the instrumented watershed, and compare results to those from the 2001 soil survey, to determine if salinity/sodicity has increased, perhaps in late 2003. This soil survey could include only those locations where salinity was evident (bottom of the structure, first bench and uppermost slope). Also of value, would be chemical analyses of the water found in access tubes (tube locations 1, 6 and 13, where standing water was found) and analysis of the water quality in the 2 waterways and toe ditch. It would be interesting to compare electrical conductivity and sodium/chloride concentrations between, for example, tube location 6 and the nearby waterway. In addition, a biogeochemical survey of the site could help determine the status of nutrients and provide a link between the nutrient and moisture regimes. The focus should begin with nitrogen; whether or not it is deficient and available to plants.

Other research, ongoing at and adjacent to the instrumented watershed, includes a groundwater and water quality study (which will identify the paths of water flow), an assessment of the vegetation (correlating the species present and their condition to the sites soil chemistry and moisture regime), as well as a comparison between the hydrology, soil chemistry and vegetation on the instrumented watershed to those on a west-facing slope of the SWSS, which has considerably less topsoil.

Ultimately, to tie together the hydrology, nutrients, vegetation and meteorology on this site, and relate this to the entire SWSS structure, modeling of these components would be needed. In this respect, processes and trends identified could be used to

simulate what the SWSS might be like in the future; in terms of the hydrologic regime, soil chemistry, and forest growth and viability.

6.0 APPENDIX

Table 6.1 Daily meteorological data from the instrumented watershed, 2001

Julian Day	Date	max air T (°C)	min air T (°C)	Ave air T (°C)	Ave Wspd (m/s)	Ave Wdir (deg. From N)	Total rad^n (MJ/m^2)	Daily precip. (mm)	Cumul. rain (mm)	Daily Penman PE (mm)	Cumul. Penman PE (mm)
183	1-Jul-01				3.28	172	12.9	0.3	0.3	5.4	13.5
184	2-Jul-01				1.56	113	13.7	0.0	0.3	5.6	19.1
185	3-Jul-01				2.83	204	14.1	0.8	1.0	6.1	25.2
186	4-Jul-01				3.82	298	7.8	0.8	1.8	4.0	29.2
187	5-Jul-01				5.16	292	9.9	0.0	1.8	5.7	35.0
188	6-Jul-01				3.32	298	9.2	0.0	1.8	4.5	39.4
189	7-Jul-01				4.15	252	9.5	0.0	1.8	5.2	44.6
190	8-Jul-01				1.91	256	10.9	0.0	1.8	4.8	49.5
191	9-Jul-01				2.71	219	10.8	0.5	2.3	4.8	54.3
192	10-Jul-01	21.4	15.3	18.6	2.82	235	2.5	2.5	4.8	1.8	56.1
193	11-Jul-01	24.9	10.3	18.3	3.03	243	13.4	0.0	4.8	6.0	62.1
194	12-Jul-01	26.9	10.6	19.7	2.23	161	11.7	0.0	4.8	5.2	67.2
195	13-Jul-01	23.1	14.5	17.7	1.44	188	6.0	7.4	12.2	2.5	69.7
196	14-Jul-01	28.8	13.3	20.5	1.89	224	13.8	0.0	12.2	5.5	75.2
197	15-Jul-01	26.3	14.7	20.2	1.81	200	6.5	3.8	16.0	2.8	78.0
198	16-Jul-01	25.1	16.4	19.3	1.68	103	4.9	4.8	20.8	1.9	79.9
199	17-Jul-01	25.2	13.0	19.6	1.91	147	10.2	0.3	21.1	4.1	84.0
200	18-Jul-01	23.6	14.1	18.6	2.52	145	10.6	2.5	23.6	4.2	88.2
201	19-Jul-01	23.5	10.3	17.9	1.55	215	7.8	0.0	23.6	3.1	91.3
202	20-Jul-01	22.3	13.1	17.4	2.20	185	5.5	0.5	24.1	2.1	93.4
203	21-Jul-01	19.3	12.0	15.2	3.00	107	11.1	0.0	24.1	4.4	97.8
204	22-Jul-01	23.9	8.4	16.6	2.22	191	12.5	0.0	24.1	5.0	102.8
205	23-Jul-01	26.1	9.4	18.8	1.97	138	11.6	0.0	24.1	4.9	107.7
206	24-Jul-01	26.2	12.7	18.2	1.48	102	8.3	6.1	30.2	3.4	111.1
207	25-Jul-01	21.5	10.6	15.8	1.01	163	6.4	1.0	31.2	2.3	113.4
208	26-Jul-01	24.0	12.0	17.5	1.14	126	12.0	0.0	31.2	4.3	117.7
209	27-Jul-01	26.2	13.3	18.3	1.76	170	10.5	12.5	43.7	4.0	121.7
210	28-Jul-01	17.1	13.4	14.8	4.05	163	-0.3	10.4	54.1	0.1	121.9
211	29-Jul-01	24.6	12.7	18.4	3.55	281	11.5	1.8	55.9	4.8	126.7
212	30-Jul-01	24.4	11.1	17.9	2.33	221	11.4	0.3	56.1	4.6	131.3
213	31-Jul-01	26.8	11.7	19.3	1.82	195	7.7	0.0	56.1	3.5	134.8

Table 6.1 (continued)

Julian Day	Date	max air T (°C)	min air T (°C)	Ave air T (°C)	Ave Wspd (m/s)	Ave Wdir (deg. From N)	Total rad^n (MJ/m^2)	Daily precip. (mm)	Cumul. rain (mm)	Daily Penman PE (mm)	Cumul. Penman PE (mm)
214	1-Aug-01	27.6	12.3	20.1	1.89	200	8.5	0.3	56.4	3.8	138.6
215	2-Aug-01	26.5	13.1	20.0	2.25	190	10.0	0.0	56.4	4.5	143.0
216	3-Aug-01	25.8	14.0	18.2	2.16	149	8.5	10.9	67.3	3.2	146.2
217	4-Aug-01	22.8	12.0	17.1	4.54	234	10.4	0.3	67.6	4.9	151.1
218	5-Aug-01	24.8	12.2	19.0	3.97	246	8.8	0.0	67.6	4.9	156.0
219	6-Aug-01	23.7	13.1	16.9	3.61	225	6.7	1.5	69.1	3.3	159.3
220	7-Aug-01	18.3	10.5	13.7	3.06	290	6.0	1.8	70.9	2.6	161.8
221	8-Aug-01	25.1	10.1	15.9	3.37	234	6.2	0.3	71.1	2.9	164.8
222	9-Aug-01	22.4	12.0	17.2	2.19	213	5.9	0.0	71.1	2.6	167.4
223	10-Aug-01	19.2	10.8	14.6	1.54	144	10.4	0.0	71.1	3.9	171.3
224	11-Aug-01	27.3	8.0	18.0	1.27	188	9.8	0.0	71.1	3.9	175.2
225	12-Aug-01	26.7	15.0	20.8	1.79	180	9.4	0.0	71.1	4.0	179.1
226	13-Aug-01	22.2	14.0	17.5	2.51	215	8.1	0.8	71.9	3.4	182.5
227	14-Aug-01	29.7	9.8	19.9	2.05	210	9.3	3.3	75.2	4.0	186.6
228	15-Aug-01	26.8	13.5	20.1	1.86	226	10.3	0.0	75.2	4.4	190.9
229	16-Aug-01	31.2	11.4	21.5	1.22	186	9.9	0.0	75.2	4.2	195.1
230	17-Aug-01	26.8	13.9	20.3	1.26	178	5.6	0.0	75.2	2.6	197.8
231	18-Aug-01	18.6	10.6	14.5	3.62	257	2.3	13.2	88.4	1.1	198.8
232	19-Aug-01	18.8	10.2	13.4	4.58	239	4.3	2.5	90.9	2.0	200.8
233	20-Aug-01	21.3	8.5	14.2	2.50	206	8.7	0.0	90.9	3.3	204.1
234	21-Aug-01	22.3	7.0	14.8	1.79	98	5.8	0.0	90.9	2.4	206.6
235	22-Aug-01	26.9	12.4	17.4	2.12	193	5.8	9.9	100.8	2.4	209.0
236	23-Aug-01	20.2	10.2	15.0	4.59	236	6.9	0.0	100.8	3.4	212.4
237	24-Aug-01	21.1	10.5	15.6	5.44	247	6.8	0.0	100.8	4.2	216.5
238	25-Aug-01	21.9	8.8	15.7	2.83	247	4.2	0.0	100.8	2.3	218.8
239	26-Aug-01	27.6	10.5	18.2	2.40	225	5.4	0.0	100.8	2.7	221.5
240	27-Aug-01	19.2	13.8	16.3	3.46	269	1.9	0.0	100.8	1.4	222.9
241	28-Aug-01	21.5	11.3	16.0	2.46	208	6.3	0.0	100.8	2.7	225.5
242	29-Aug-01	24.0	7.1	15.9	1.88	166	6.3	0.0	100.8	2.7	228.2
243	30-Aug-01	21.7	11.8	16.4	1.84	157	4.8	0.0	100.8	2.2	230.4
244	31-Aug-01	21.4	12.2	16.2	2.89	234	3.2	3.8	104.7	1.9	232.3

* Potential evapotranspiration (PE) was calculated using the Penman-Monteith equation.

Table 6.1 (continued)

Julian Day	Date	max air T (°C)	min air T (°C)	Ave air T (°C)	Ave Wspd (m/s)	Ave Wdir (deg. From N)	Total rad^n (MJ/m^2)	Daily precip. (mm)	Cumul. rain (mm)	Daily Penman PE (mm)	Cumul. Penman PE (mm)
245	1-Sep-01	20.0	8.5	14.0	4.63	252	6.1	0.0	104.7	3.3	235.6
246	2-Sep-01	17.8	4.5	11.2	2.02	188	0.5	0.8	105.4	0.8	236.4
247	3-Sep-01	18.8	8.5	13.5	3.84	232	4.8	0.0	105.4	3.1	239.5
248	4-Sep-01	19.5	6.9	12.5	3.48	252	5.1	0.0	105.4	2.8	242.3
249	5-Sep-01	12.4	6.4	9.9	3.03	246	0.4	0.5	105.9	0.7	242.9
250	6-Sep-01	16.7	8.6	11.4	2.31	238	3.6	1.8	107.7	1.4	244.4
251	7-Sep-01	17.0	7.9	11.7	3.75	240	4.0	0.3	108.0	2.1	246.5
252	8-Sep-01	13.3	5.9	8.9	2.62	264	2.8	0.5	108.5	1.2	247.7
253	9-Sep-01	14.9	6.8	9.2	1.66	264	2.4	2.8	111.3	0.9	248.6
254	10-Sep-01	12.2	6.6	9.0	1.91	195	3.7	0.3	111.5	1.3	249.9
255	11-Sep-01	13.6	7.1	9.7	1.20	214	2.6	0.0	111.5	1.0	250.9
256	12-Sep-01	20.3	6.7	13.0	2.73	183	5.1	0.0	111.5	2.4	253.3
257	13-Sep-01	25.0	8.6	15.8	2.52	238	4.3	0.0	111.5	2.4	255.6
258	14-Sep-01	27.1	5.9	16.1	1.82	216	4.1	0.0	111.5	2.2	257.8
259	15-Sep-01	16.3	8.0	11.0	2.06	153	4.0	0.0	111.5	1.8	259.6
260	16-Sep-01	21.0	3.3	12.1	1.32	171	4.1	0.0	111.5	1.8	261.4
261	17-Sep-01	21.4	5.9	12.3	1.37	201	3.4	4.6	116.1	1.4	262.8
262	18-Sep-01	12.6	7.5	9.1	2.41	204	0.4	2.3	118.4	0.1	262.9
263	19-Sep-01	13.6	5.9	8.9	2.21	285	4.4	0.0	118.4	1.5	264.4
264	20-Sep-01	10.8	5.4	7.5	1.76	145	2.9	0.0	118.4	1.1	265.5
265	21-Sep-01	16.0	1.1	8.1	2.56	151	2.6	0.0	118.4	1.2	266.7
266	22-Sep-01	23.5	5.1	14.1	2.10	172	3.8	0.0	118.4	1.9	268.6
267	23-Sep-01	21.5	7.7	14.6	1.73	173	3.9	0.0	118.4	2.0	270.6
268	24-Sep-01	26.0	7.3	15.9	1.02	197	3.4	0.0	118.4	1.7	272.3
269	25-Sep-01	30.3	7.3	17.4	2.62	176	2.2	0.0	118.4	1.8	274.2
270	26-Sep-01	16.5	8.1	12.7	4.50	223	0.3	0.0	118.4	1.2	275.4
271	27-Sep-01	17.8	2.2	10.4	1.83	230	2.0	0.0	118.4	1.4	276.8
272	28-Sep-01	19.3	3.4	11.3	2.21	201	1.8	0.0	118.4	1.3	278.1
273	29-Sep-01	15.7	7.1	11.9	5.47	250	0.4	0.0	118.4	2.4	280.5
274	30-Sep-01	14.9	3.7	8.4	4.04	257	-0.3	0.0	118.4	1.3	281.9

* Potential evapotranspiration (PE) was calculated using the Penman-Monteith equation.

Table 6.2 Daily meteorological data from the instrumented watershed, 2002

Julian Day	Date	max air T (°C)	min air T (°C)	Ave air T (°C)	Ave Wspd (m/s)	Ave Wdir (deg. From N)	Total rad^n (MJ/m^2)	Daily precip. (mm)	Cumul. rain (mm)	Daily Penman PE (mm)	Cumul. Penman PE (mm)
91	1-Apr-02	-11	-18	-15	4	174	4	0	10.9	1.0	11.4
92	2-Apr-02	-7	-19	-13	1	185	5	0	10.9	1.0	12.4
93	3-Apr-02	-2	-15	-8	1	196	5	0	10.9	1.3	13.8
94	4-Apr-02	-4	-11	-8	2	125	5	0	10.9	1.3	15.1
95	5-Apr-02	-3	-16	-9	2	169	5	0	10.9	1.4	16.4
96	6-Apr-02	-2	-12	-7	2	103	4	0	10.9	1.0	17.5
97	7-Apr-02	-1	-11	-6	2	174	5	0	10.9	1.2	18.7
98	8-Apr-02	0	-16	-7	2	244	6	0	10.9	1.6	20.2
99	9-Apr-02	2	-16	-6	2	197	6	0	10.9	1.8	22.0
100	10-Apr-02	8	-4	1	2	177	4	0	10.9	1.7	23.7
101	11-Apr-02	10	-1	6	5	277	8	0	10.9	3.7	27.4
102	12-Apr-02	13	-3	5	2	185	4	0	10.9	1.8	29.2
103	13-Apr-02	6	-2	1	3	73	3	0	10.9	1.1	30.3
104	14-Apr-02	7	-4	1	3	53	7	0	10.9	2.6	32.9
105	15-Apr-02	3	-7	-3	4	53	6	0	10.9	2.3	35.2
106	16-Apr-02	0	-10	-5	2	115	6	0	10.9	1.6	36.8
107	17-Apr-02	2	-6	-2	3	223	8	0	10.9	2.5	39.3
108	18-Apr-02	5	-6	-1	2	214	8	0	10.9	2.6	41.9
109	19-Apr-02	12	-7	3	2	182	8	0	10.9	3.1	45.0
110	20-Apr-02	17	-3	8	3	194	9	0	10.9	4.0	49.0
111	21-Apr-02	13	2	8	2	210	5	0	10.9	2.2	51.1
112	22-Apr-02	8	-9	0	3	142	4	0	10.9	1.2	52.3
113	23-Apr-02	-5	-11	-8	5	281	6	0	10.9	1.7	54.0
114	24-Apr-02	-1	-12	-7	3	170	9	0	10.9	2.4	56.5
115	25-Apr-02	6	-11	-2	2	167	7	0	10.9	2.3	58.7
116	26-Apr-02	5	-7	-1	2	211	8	0	10.9	2.5	61.3
117	27-Apr-02	10	-4	4	4	239	8	0	10.9	3.6	64.9
118	28-Apr-02	9	1	5	4	264	6	0	10.9	2.5	67.4
119	29-Apr-02	8	0	3	4	264	7	0	10.9	2.8	70.2
120	30-Apr-02	2	-5	-1	4	95	11	0	10.9	3.6	73.7

* Potential evapotranspiration (PE) was calculated using the Penman-Monteith equation.

Table 6.2 (continued)

Julian Day	Date	max air T (°C)	min air T (°C)	Ave air T (°C)	Ave Wspd (m/s)	Ave Wdir (deg. From N)	Total rad^n (MJ/m^2)	Daily precip. (mm)	Cumul. rain (mm)	Daily Penman PE (mm)	Cumul. Penman PE (mm)
121	1-May-02	8	-6	2	3	142	9	0	10.9	3.2	77.0
122	2-May-02	4	-7	0	5	250	4	0	10.9	1.9	78.8
123	3-May-02	-3	-10	-7	4	309	7	0	10.9	2.2	81.0
124	4-May-02	2	-11	-4	3	186	10	0	10.9	3.0	84.0
125	5-May-02	3	-9	-3	4	51	11	0	10.9	3.4	87.5
126	6-May-02	6	-7	-1	2	160	11	0	10.9	3.2	90.6
127	7-May-02	10	-4	3	2	267	10	0	10.9	3.5	94.1
128	8-May-02	13	-3	5	2	173	9	0	10.9	3.5	97.6
129	9-May-02	14	-2	6	2	245	9	0	10.9	3.7	101.3
130	10-May-02	16	2	9	2	222	10	0	10.9	4.1	105.4
131	11-May-02	14	2	8	3	236	5	0	10.9	2.3	107.7
132	12-May-02	18	2	11	2	227	11	0	10.9	4.3	112.1
133	13-May-02	21	9	15	2	115	9	0	10.9	4.5	116.6
134	14-May-02	13	2	8	5	58	12	0	10.9	4.9	121.5
135	15-May-02	16	-2	7	2	157	11	0	10.9	4.0	125.6
136	16-May-02	21	3	13	3	146	11	0	10.9	5.2	130.7
137	17-May-02	21	5	14	4	141	10	0	10.9	5.5	136.2
138	18-May-02	22	8	15	4	140	9	0	10.9	5.4	141.6
139	19-May-02	15	9	12	3	148	0	0	10.9	1.7	143.3
140	20-May-02	14	7	10	3	146	3	0	10.9	1.8	145.0
141	21-May-02	10	1	5	5	40	12	0	10.9	5.1	150.1
142	22-May-02	8	-2	3	4	94	12	0	10.9	4.5	154.6
143	23-May-02	13	-2	6	2	214	10	0	10.9	3.7	158.3
144	24-May-02	16	4	10	2	250	9	0	10.9	4.2	162.5
145	25-May-02	13	6	9	3	263	9	0	10.9	4.1	166.6
146	26-May-02	23	4	15	4	215	6	0	10.9	4.5	171.1
147	27-May-02	15	4	10	5	49	11	0	10.9	5.3	176.3
148	28-May-02	23	3	13	3	85	11	0	10.9	4.9	181.2
149	29-May-02	21	11	15	3	233	4	7	18.3	2.3	183.5
150	30-May-02	19	7	13	4	275	8	0	18.5	3.2	186.7
151	31-May-02	15	6	11	3	198	4	2	20.8	1.7	188.4

* Potential evapotranspiration (PE) was calculated using the Penman-Monteith equation.

Table 6.2 (continued)

Julian Day	Date	max air T (°C)	min air T (°C)	Ave air T (°C)	Ave Wspd (m/s)	Ave Wdir (deg. From N)	Total rad^n (MJ/m^2)	Daily precip. (mm)	Cumul. rain (mm)	Daily Penman PE (mm)	Cumul. Penman PE (mm)
152	1-Jun-02	19	3	11	2	141	10	0	21.1	3.5	192.0
153	2-Jun-02	22	6	14	2	166	11	0	21.1	4.5	196.5
154	3-Jun-02	24	7	15	2	184	9	1	22.1	4.0	200.5
155	4-Jun-02	26	10	18	2	178	10	0	22.1	4.6	205.1
156	5-Jun-02	27	11	18	2	180	9	4	26.4	4.0	209.0
157	6-Jun-02	14	10	11	2	193	2	8	34.6	0.9	209.9
158	7-Jun-02	21	9	13	3	180	9	7	41.2	3.2	213.1
159	8-Jun-02	23	6	15	2	165	14	0	41.2	5.4	218.6
160	9-Jun-02	23	10	17	2	121	14	0	41.2	6.1	224.6
161	10-Jun-02	25	11	18	2	149	14	0	41.2	6.0	230.6
162	11-Jun-02	26	9	19	1	158	12	0	41.2	5.5	236.1
163	12-Jun-02	29	10	21	2	193	10	0	41.2	5.4	241.6
164	13-Jun-02	23	13	19	3	126	14	0	41.2	6.6	248.1
165	14-Jun-02	23	10	16	2	178	10	0	41.2	4.4	252.6
166	15-Jun-02	23	10	16	2	149	7	1	42.4	3.1	255.6
167	16-Jun-02	20	9	13	3	98	11	0	42.4	4.2	259.9
168	17-Jun-02	16	6	11	2	122	5	3	45.7	2.0	261.9
169	18-Jun-02	20	6	14	2	215	13	0	45.7	5.1	266.9
170	19-Jun-02	18	7	13	3	244	6	1	47.0	3.0	269.9
171	20-Jun-02	25	6	16	4	228	11	0	47.3	5.3	275.2
172	21-Jun-02	27	9	18	3	202	11	0	47.3	4.9	280.1
173	22-Jun-02	29	8	19	2	202	13	0	47.3	5.6	285.7
174	23-Jun-02	33	16	24	3	163	9	1	48.5	5.4	291.2
175	24-Jun-02	27	16	21	3	227	5	1	49.3	2.9	294.1
176	25-Jun-02	28	14	22	4	253	12	0	49.3	6.7	300.9
177	26-Jun-02	32	14	24	2	196	10	0	49.3	4.9	305.8
178	27-Jun-02	35	17	25	3	229	10	0	49.3	5.8	311.6
179	28-Jun-02	26	16	20	3	254	3	3	52.6	2.1	313.7
180	29-Jun-02	26	13	18	2	212	10	1	53.9	4.0	317.7
181	30-Jun-02	17	13	15	3	268	2	16	69.9	1.0	318.7

* Potential evapotranspiration (PE) was calculated using the Penman-Monteith equation.

Table 6.2 (continued)

Julian Day	Date	max air T (°C)	min air T (°C)	Ave air T (°C)	Ave Wspd (m/s)	Ave Wdir (deg. From N)	Total rad^n (MJ/m^2)	Daily precip. (mm)	Cumul. rain (mm)	Daily Penman PE (mm)	Cumul. Penman PE (mm)
182	1-Jul-02	14	10	12	4	262	0	16	85.6	0.4	319.2
183	2-Jul-02	18	8	12	2	157	10	1	86.1	3.4	322.5
184	3-Jul-02	23	7	15	2	201	12	0	86.1	4.7	327.3
185	4-Jul-02	19	12	14	2	155	2	5	90.7	1.1	328.4
186	5-Jul-02	17	10	14	5	239	10	0	90.7	4.5	332.8
187	6-Jul-02	21	11	16	3	254	7	3	93.7	3.2	336.0
188	7-Jul-02	27	9	19	2	229	13	0	93.7	5.5	341.5
189	8-Jul-02	30	12	22	1	173	13	0	93.7	5.7	347.2
190	9-Jul-02	28	16	23	3	178	10	0	93.7	5.6	352.8
191	10-Jul-02	31	16	25	4	235	12	0	93.7	6.8	359.6
192	11-Jul-02	31	16	23	2	193	11	0	93.7	5.3	364.9
193	12-Jul-02	30	17	24	3	272	9	0	93.7	5.0	369.9
194	13-Jul-02	26	13	20	2	114	12	1	94.2	5.1	375.0
195	14-Jul-02	21	16	18	3	173	5	2	95.8	2.4	377.4
196	15-Jul-02	21	12	17	5	266	9	0	95.8	5.3	382.7
197	16-Jul-02	22	8	15	2	180	11	0	95.8	4.3	387.0
198	17-Jul-02	27	12	19	2	110	9	0	95.8	4.1	391.1
199	18-Jul-02	21	13	16	2	122	7	10	105.7	2.4	393.5
200	19-Jul-02	20	13	16	2	181	8	0	105.7	2.9	396.4
201	20-Jul-02	14	12	13	4	267	-2	26	131.3	-0.2	396.2
202	21-Jul-02	22	11	17	2	161	14	0	131.3	5.4	401.6
203	22-Jul-02	28	10	20	1	207	12	0	131.3	5.0	406.6
204	23-Jul-02	25	16	20	3	207	6	0	131.3	3.3	409.9
205	24-Jul-02	29	14	22	2	268	12	0	131.3	5.5	415.4
206	25-Jul-02	30	16	22	2	245	10	1	132.6	4.5	419.9
207	26-Jul-02	24	15	18	3	259	7	1	133.4	3.1	423.0
208	27-Jul-02	20	13	15	3	257	5	9	142.2	1.9	424.9
209	28-Jul-02	21	13	17	4	260	10	8	150.4	4.2	429.1
210	29-Jul-02	20	9	14	5	264	10	0	150.4	4.7	433.9
211	30-Jul-02	11	7	9	6	257	1	16	166.1	0.6	434.5
212	31-Jul-02	12	8	9	4	296	1	4	170.2	0.7	435.2

* Potential evapotranspiration (PE) was calculated using the Penman-Monteith equation.

Table 6.2 (continued)

Julian Day	Date	max air T (°C)	min air T (°C)	Ave air T (°C)	Ave Wspd (m/s)	Ave Wdir (deg. From N)	Total rad^n (MJ/m^2)	Daily precip. (mm)	Cumul. rain (mm)	Daily Penman PE (mm)	Cumul. Penman PE (mm)
213	1-Aug-02	14	5	9	4	261	9	0	170.2	3.5	438.7
214	2-Aug-02	12	2	7	2	275	6	0	170.4	2.2	440.9
215	3-Aug-02	14	6	10	2	264	7	0	170.4	2.5	443.4
216	4-Aug-02	17	6	12	2	188	10	0	170.4	3.9	447.3
217	5-Aug-02	13	8	10	1	129	-1	7	177.6	0.0	447.3
218	6-Aug-02	22	8	15	2	214	10	0	177.8	4.0	451.3
219	7-Aug-02	27	9	18	2	187	10	0	177.8	4.3	455.6
220	8-Aug-02	27	8	19	2	214	10	0	177.8	4.5	460.1
221	9-Aug-02	26	15	20	4	246	6	0	177.8	3.9	464.0
222	10-Aug-02	22	11	16	4	272	8	0	177.8	4.0	468.1
223	11-Aug-02	22	9	16	3	279	9	0	177.8	4.1	472.2
224	12-Aug-02	22	10	17	3	261	8	0	177.8	3.5	475.7
225	13-Aug-02	24	13	17	3	245	3	0	178.1	1.9	477.6
226	14-Aug-02	15	11	13	3	244	-1	2	180.3	0.2	477.8
227	15-Aug-02	16	7	11	2	251	5	7	187.5	1.8	479.6
228	16-Aug-02	15	4	9	2	283	7	2	189.5	2.5	482.0
229	17-Aug-02	13	4	8	1	173	3	1	190.8	1.1	483.2
230	18-Aug-02	21	4	13	2	247	6	0	190.8	2.6	485.7
231	19-Aug-02	13	7	11	2	168	3	2	192.3	1.4	487.1
232	20-Aug-02	20	5	12	1	233	8	0	192.5	2.8	490.0
233	21-Aug-02	25	8	17	2	167	9	0	192.5	3.8	493.7
234	22-Aug-02	26	14	20	3	260	8	0	192.5	4.2	497.9
235	23-Aug-02	28	12	21	3	234	8	0	192.5	4.2	502.2
236	24-Aug-02	27	16	22	2	283	8	0	192.5	4.4	506.6
237	25-Aug-02	18	10	14	1	211	1	5	197.9	0.6	507.1
238	26-Aug-02	24	13	18	1	174	8	3	200.7	2.7	509.8
239	27-Aug-02	27	12	20	1	229	8	0	200.7	3.2	513.0
240	28-Aug-02	30	13	21	2	185	6	0	200.7	3.0	515.9
241	29-Aug-02	30	15	23	2	220	8	0	200.7	3.9	519.9
242	30-Aug-02	19	13	16	2	235	1	3	203.7	0.8	520.7
243	31-Aug-02	24	10	17	3	232	7	0	204.0	3.2	523.9

* Potential evapotranspiration (PE) was calculated using the Penman-Monteith equation.

Table 6.2 (continued)

Julian Day	Date	max air T (°C)	min air T (°C)	Ave air T (°C)	Ave Wspd (m/s)	Ave Wdir (deg. From N)	Total rad^n (MJ/m^2)	Daily precip. (mm)	Cumul. rain (mm)	Daily Penman PE (mm)	Cumul. Penman PE (mm)
244	1-Sep-02	21	12	16	4	253	6	0	204.0	3.1	527.0
245	2-Sep-02	18	9	13	3	220	4	1	205.0	1.9	529.0
246	3-Sep-02	13	8	11	2	152	2	10	215.1	0.8	529.8
247	4-Sep-02	15	10	12	2	201	3	13	227.8	1.0	530.8
248	5-Sep-02	14	8	10	2	232	4	2	229.4	1.5	532.2
249	6-Sep-02	14	8	10	1	197	4	3	232.7	1.3	533.5
250	7-Sep-02	18	4	11	2	178	5	1	233.9	1.9	535.5
251	8-Sep-02	18	8	13	3	225	4	0	233.9	2.2	537.7
252	9-Sep-02	19	9	14	4	239	5	0	233.9	2.9	540.6
253	10-Sep-02	24	10	16	3	234	5	1	234.7	2.9	543.5
254	11-Sep-02	20	8	13	4	256	4	0	234.7	2.5	546.1
255	12-Sep-02	19	6	12	3	243	3	0	234.7	1.8	547.8
256	13-Sep-02	18	9	13	3	276	5	0	235.0	2.5	550.4
257	14-Sep-02	21	2	13	2	199	4	0	235.0	2.1	552.5
258	15-Sep-02	22	11	16	3	233	4	0	235.0	2.5	555.0
259	16-Sep-02	19	9	13	1	178	1	1	236.0	0.7	555.7
260	17-Sep-02	19	7	13	3	255	4	0	236.0	2.3	557.9
261	18-Sep-02	18	7	12	4	237	3	0	236.0	2.5	560.5
262	19-Sep-02	14	6	10	4	254	2	3	239.3	1.6	562.0
263	20-Sep-02	11	6	7	5	291	2	2	241.6	1.1	563.1
264	21-Sep-02	10	4	6	3	308	3	0	241.6	1.5	564.6
265	22-Sep-02	9	2	5	3	299	2	0	241.6	1.1	565.8
266	23-Sep-02	11	0	4	4	279	1	0	241.6	0.9	566.7
267	24-Sep-02	5	-4	0	3	289	2	0	241.6	1.2	567.9
268	25-Sep-02	8	-5	1	3	264	2	0	241.6	1.2	569.2
269	26-Sep-02	7	-5	0	2	256	1	0	241.6	0.7	569.9
270	27-Sep-02	9	-1	3	2	184	3	0	241.6	1.3	571.2
271	28-Sep-02	13	2	7	2	175	1	8	249.4	0.8	572.0
272	29-Sep-02	11	4	7	2	211	2	2	251.2	0.9	572.8
273	30-Sep-02	8	0	3	1	205	2	0	251.2	0.8	573.6

* Potential evapotranspiration (PE) was calculated using the Penman-Monteith equation.

Table 6.3 Statistical analysis for TSW40 (mm)

✓ = statistically significant variation ($\alpha = 0.05$)

Dates	09-Jun-01	20-Jun-01	04-Jul-01	23-Jul-01	14-Aug-01	27-Aug-01	21-Sep-01	24-May-02	04-Jun-02	18-Jun-02	16-Jul-02	29-Jul-02	13-Aug-02	27-Aug-02	13-Sep-02
Model				✓	✓	✓	✓				✓	✓	✓	✓	✓
R^2	0.39	0.37	0.42	0.48	0.47	0.53	0.54	0.41	0.39	0.44	0.53	0.53	0.49	0.62	0.45
rep															
tube				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
LSMeans	6 121	11 116	6 79	13 107	13 107	13 107	6 110	6 129	6 120	6 120	6 102	6 116	13 112	6 134	6 118
(tube)	4 117	6 115	13 76	6 105	6 105	6 106	13 109	9 118	13 118	13 113	13 102	13 110	6 111	13 107	13 118
	9 117	13 113	9 73	7 86	1 86	1 85	1 86	13 118	9 110	4 94	1 85	12 103	12 101	12 104	12 108
	13 114	4 109	1 72	1 83	9 83	11 80	2 78	4 114	2 103	1 93	2 75	1 101	11 96	5 102	1 105
	2 114	2 108	2 71	11 82	2 79	2 79	11 77	2 104	4 101	9 91	11 73	11 95	1 94	1 94	11 101
	1 107	9 106	4 69	5 81	11 78	7 78	5 75	5 97	5 96	2 90	5 73	4 94	4 90	11 92	5 97
	5 107	5 102	7 68	2 79	5 77	5 75	7 74	1 94	1 95	10 84	7 73	2 93	5 89	4 88	9 97
	12 105	12 101	5 67	9 79	10 74	12 74	9 69	10 94	10 92	5 84	12 72	9 90	2 88	2 86	4 96
	8 97	1 100	12 66	12 79	12 73	9 73	4 68	12 86	12 86	12 83	4 65	5 89	7 82	7 84	2 96
	11 96	10 93	11 65	8 77	4 70	10 73	12 68	7 85	7 82	7 81	10 64	10 84	9 81	9 82	7 85
	10 95	7 86	8 62	10 76	8 69	4 68	10 66	8 84	11 81	11 75	8 61	7 80	10 81	8 73	10 82
	7 93	8 83	10 59	4 75	7 68	8 66	8 64	3 80	8 77	8 73	9 61	8 69	3 75	10 72	8 81
	3 92	3 82	3 56	3 62	3 61	3 59	3 57	11 79	3 71	3 57	3 58	3 67	8 73	3 67	3 77
Contrasts															
slope: A vs C								✓	✓	✓				✓	
slope: B vs D	✓		✓												
slope: A vs E				✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
slope: C vs E				✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
tubes: 1 vs 2															
tubes: 1 vs 3			✓		✓	✓	✓			✓	✓	✓		✓	✓
tubes: 2 vs 3			✓							✓		✓			
tubes: 4 vs 5			✓												
tubes: 4 vs 6			✓	✓	✓	✓	✓				✓			✓	
tubes: 5 vs 6				✓	✓	✓	✓			✓	✓	✓		✓	
tubes: 7 vs 8															
tubes: 7 vs 9															
tubes: 8 vs 9								✓	✓						
tubes: 10 vs 11															
tubes: 10 vs 12														✓	✓
tubes: 11 vs 12															
tubes: 2 vs 13				✓	✓	✓	✓				✓		✓		
tubes: 8 vs 13		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
tubes: 3 vs 4	✓									✓		✓			
tubes: 9 vs 10			✓												
tubes: 6 vs 7	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
tubes: 12 vs 13				✓	✓	✓	✓	✓		✓	✓				

Table 6.4 Statistical analysis for TSW120 (mm)

✓ = statistically significant variation ($\alpha = 0.05$)

Dates		09-Jun-01	20-Jun-01	04-Jul-01	23-Jul-01	14-Aug-01	27-Aug-01	21-Sep-01	24-May-02	04-Jun-02	18-Jun-02	16-Jul-02	29-Jul-02	13-Aug-02	27-Aug-02	13-Sep-02
Model		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
R^2		0.81	0.82	0.81	0.83	0.83	0.84	0.84	0.74	0.74	0.79	0.84	0.81	0.81	0.86	0.78
rep			✓								✓	✓				
tube		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
LSMeans		13 444	13 440	13 387	13 415	13 406	13 418	13 420	6 467	13 446	6 451	6 418	6 449	6 439	6 490	6 438
(tube)		6 431	6 413	6 382	6 401	6 405	6 401	6 409	13 457	6 427	13 433	13 414	13 415	13 429	13 415	13 424
		5 369	5 355	5 314	5 313	5 310	5 298	5 300	5 348	5 350	5 333	5 312	5 331	5 339	5 373	5 342
		1 336	1 329	1 290	1 292	1 283	1 279	1 279	1 312	1 303	1 311	1 297	1 315	1 310	1 284	1 313
		2 318	2 300	2 258	2 236	2 228	2 226	2 226	2 287	2 293	2 280	2 230	2 258	2 249	2 236	2 257
		4 298	4 281	4 227	4 213	4 202	4 198	4 186	4 277	4 265	4 250	4 186	4 242	4 240	4 215	4 247
		3 224	3 210	3 178	7 177	7 179	7 166	3 155	3 196	9 191	3 182	3 155	3 174	3 183	12 189	3 188
		9 206	9 208	8 173	3 173	3 167	3 163	7 150	9 194	3 187	9 172	7 145	12 172	12 173	3 170	12 180
		12 206	7 198	9 167	9 171	8 157	9 159	9 142	12 183	12 174	12 162	12 138	9 170	7 161	7 159	9 177
		8 197	12 195	7 167	8 167	9 142	8 148	8 133	10 180	10 167	8 157	8 132	7 160	9 160	9 148	7 167
		7 192	8 189	12 146	12 145	12 136	10 133	12 123	8 160	8 163	7 152	9 126	8 147	8 153	8 147	8 161
		10 179	10 169	10 133	10 139	10 132	12 133	10 118	7 158	7 152	10 151	10 119	10 145	10 144	10 133	10 145
		11 135	11 153	11 98	11 106	11 101	11 102	11 98	11 97	11 101	11 95	11 92	11 118	11 121	11 111	11 129
Contrasts																
slope	A vs C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	B vs D	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	A vs E	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	C vs E	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
tubes	1 vs 2											✓				
	1 vs 3	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
	2 vs 3	✓	✓	✓								✓				
	4 vs 5			✓	✓	✓	✓	✓				✓	✓	✓	✓	✓
	4 vs 6	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	5 vs 6				✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
	7 vs 8															
	7 vs 9															
	8 vs 9															
	10 vs 11															
	10 vs 12															
	11 vs 12															
	2 vs 13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	8 vs 13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	3 vs 4															
	9 vs 10															
	6 vs 7	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	12 vs 13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

moisture ↑

Table 6.5 Statistical analysis for TSW80-120 (mm)

✓ = statistically significant variation ($\alpha = 0.05$)

Dates		09-Jun-01	20-Jun-01	04-Jul-01	23-Jul-01	14-Aug-01	27-Aug-01	21-Sep-01	24-May-02	04-Jun-02	18-Jun-02	16-Jul-02	29-Jul-02	13-Aug-02	27-Aug-02	13-Sep-02
Model		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
R^2		0.81	0.85	0.81	0.84	0.80	0.84	0.83	0.81	0.80	0.80	0.84	0.83	0.83	0.86	0.82
rep		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
tube		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
LSMeans		13 171	13 169	13 163	13 166	6 157	13 167	13 169	6 175	13 172	6 175	13 171	6 185	6 177	6 189	6 169
(tube)		6 157	6 162	6 155	6 153	13 157	6 152	6 156	13 172	6 148	13 172	6 169	13 169	13 174	13 171	13 167
		5 141	5 135	5 135	5 126	5 127	5 123	5 125	5 137	5 142	5 138	5 140	5 138	5 140	5 154	5 135
		2 111	1 116	1 105	1 106	1 96	1 95	1 94	1 112	1 105	1 111	1 108	1 107	1 108	1 94	1 99
		1 108	2 96	2 93	2 68	2 69	2 68	2 76	2 88	2 93	2 93	2 74	2 76	2 73	2 84	2 77
		4 94	4 80	4 75	4 68	4 65	4 64	4 57	4 80	4 80	4 79	4 63	4 69	4 73	4 71	4 75
		12 53	12 50	10 41	12 40	12 34	12 33	12 31	10 60	10 47	3 51	10 32	12 33	10 33	3 36	3 36
		10 52	10 42	12 40	10 32	7 34	3 29	10 27	12 55	12 45	10 39	3 29	3 32	12 32	10 33	10 32
		3 47	3 37	3 39	3 31	3 30	10 27	3 26	3 40	3 39	12 30	12 29	10 30	3 29	12 30	12 30
		8 25	8 22	8 23	8 22	10 29	8 22	9 19	8 18	8 18	8 19	8 18	9 21	8 21	9 25	9 23
		7 19	7 15	9 15	9 15	8 24	9 15	8 17	9 13	9 11	9 17	9 17	8 20	9 18	8 16	8 17
		9 17	9 14	7 14	7 12	9 17	7 13	7 11	11 7	11 6	11 7	7 9	7 13	7 11	7 15	7 15
		11 9	11 7	11 8	11 7	11 6	11 7	11 7	7 6	7 5	7 6	11 6	11 6	11 7	11 4	11 7
Contrasts																
slope	A vs C	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	B vs D	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	A vs E	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	C vs E	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
tubes	1 vs 2															
	1 vs 3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	2 vs 3	✓	✓	✓				✓							✓	
	4 vs 5		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	4 vs 6	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	5 vs 6															
	7 vs 8															
	7 vs 9															
	8 vs 9															
	10 vs 11															
	10 vs 12															
	11 vs 12															
	2 vs 13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	8 vs 13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	3 vs 4															
	9 vs 10															
	6 vs 7	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	12 vs 13	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
LSMeans		3 91	4 81	4 89	1 85	4 81	1 77	1 81	4 91	1 85	1 76	1 79	3 93	1 77	4 85	1 87
(rep)		1 79	3 80	3 86	4 78	1 80	4 75	4 80	3 82	3 84	4 73	3 75	1 83	3 73	1 84	4 78
		4 77	1 78	1 83	3 76	3 75	3 74	3 74	1 80	4 79	3 73	4 71	4 81	4 70	3 76	3 76
		2 33	2 39	2 51	2 36	2 34	2 33	2 31	2 33	2 43	2 28	2 35	2 39	2 31	2 39	2 36

moisture

Table 6.6 Statistical analysis for interface depth (cm)
✓ = statistically significant variation ($\alpha = 0.05$)

Mean 62.3	Std Dev 25.9	Std Error 3.6
Variance 669.7	Coef. Var. 41.5	

Model
p ✓
R^2 0.755
rep ✓
tube ✓

LSMeans
(rep) 4 76.2
3 75.8
2 37.8
1 30.0

Contrast
(rep) 1 vs 2 ✓
1 vs 3 ✓
1 vs 4 ✓
2 vs 3
2 vs 4
3 vs 4

LSMeans
(tube) 5 78.5
9 73.8
3 72.0
1 71.0
6 68.0
2 65.8
4 64.5
13 62.5
8 61.8
7 60.3
11 49.8
12 44.8
10 39.0

Only signif. Contrast for tubes is 5 vs 10

Table 6.7 Hourly precipitation for selected rainfall events, 2002

Jun 5 - 6		Jun 28 - 29		Jun 30 - Jul 1		Jul 19 - 20		Jul 29 - Jul 30		Sep 2 - 5	
Date and Time	*Precip. (mm)*	*Date and Time*	*Precip. (mm)*	*Date and Time*	*Precip. (mm)*	*Date and Time*	*Precip. (mm)*	*Date and Time*	*Precip. (mm)*	*Date and Time*	*Precip. (mm)*
5-Jun, 17:00	0.508	28-Jun, 23:00	0.254	30-Jun, 11:00	0.762	19-Jul, 7:00	0.254	29-Jul, 11:00	0.508	02-Sep, 23:00	2.794
5-Jun, 18:00	1.524	29-Jun, 0:00	0.508	30-Jun, 12:00	1.27	19-Jul, 8:00	0.762	29-Jul, 12:00	0.762	03-Sep, 0:00	2.032
5-Jun, 19:00	0.762	29-Jun, 1:00	0.508	30-Jun, 13:00	1.27	19-Jul, 9:00	1.27	29-Jul, 13:00	0.508	03-Sep, 1:00	5.08
5-Jun, 20:00	2.032	29-Jun, 2:00	0.254	30-Jun, 14:00	0.762	19-Jul, 10:00	1.524	29-Jul, 14:00	0.508	03-Sep, 2:00	0.254
5-Jun, 21:00	2.286	29-Jun, 3:00	0.508	30-Jun, 15:00	1.016	19-Jul, 11:00	3.302	29-Jul, 15:00	0.508	03-Sep, 3:00	2.794
5-Jun, 22:00	0.508	29-Jun, 4:00	1.016	30-Jun, 16:00	0.762	19-Jul, 12:00	2.286	29-Jul, 16:00	0.762	03-Sep, 4:00	0.254
5-Jun, 23:00	0.254	29-Jun, 5:00	1.524	30-Jun, 17:00	0.508	19-Jul, 13:00	1.27	29-Jul, 17:00	1.524	03-Sep, 5:00	
6-Jun, 0:00	0.254	29-Jun, 6:00	0.762	30-Jun, 18:00	1.016	19-Jul, 14:00	5.842	29-Jul, 18:00	0.508	03-Sep, 6:00	2.032
6-Jun, 1:00		29-Jun, 7:00	2.794	30-Jun, 19:00	2.794	19-Jul, 15:00	1.778	29-Jul, 19:00	1.016	03-Sep, 7:00	0.254
6-Jun, 2:00	0.762	29-Jun, 8:00	1.016	30-Jun, 20:00	3.81	19-Jul, 16:00	1.27	29-Jul, 20:00	1.27	03-Sep, 8:00	
6-Jun, 3:00	0.508	29-Jun, 9:00	1.524	30-Jun, 21:00	0.762	19-Jul, 17:00	2.032	29-Jul, 21:00	1.778	03-Sep, 9:00	
6-Jun, 4:00	0.762	29-Jun, 10:00	1.524	30-Jun, 22:00	0.254	19-Jul, 18:00	0.254	29-Jul, 22:00	2.286	03-Sep, 10:00	
6-Jun, 5:00	1.524	29-Jun, 11:00	2.54	30-Jun, 23:00	0.254	19-Jul, 19:00	0.254	29-Jul, 23:00	1.016	03-Sep, 11:00	
6-Jun, 6:00	2.286	29-Jun, 12:00	1.778	01-Jul, 0:00	0.254	19-Jul, 20:00	1.016	30-Jul, 0:00	1.524	03-Sep, 12:00	
6-Jun, 7:00		29-Jun, 13:00	0.508	01-Jul, 1:00	0.254	19-Jul, 21:00	1.016	30-Jul, 1:00	1.016	03-Sep, 13:00	
6-Jun, 8:00		29-Jun, 14:00	0.254	01-Jul, 2:00		19-Jul, 22:00	0.762	30-Jul, 2:00	0.508	03-Sep, 14:00	
6-Jun, 9:00				01-Jul, 3:00		19-Jul, 23:00	0.254	30-Jul, 3:00		03-Sep, 15:00	
6-Jun, 10:00				01-Jul, 4:00	0.254	20-Jul, 0:00	0.254	30-Jul, 4:00	0.254	03-Sep, 16:00	
6-Jun, 11:00				01-Jul, 5:00		20-Jul, 1:00	0.254	30-Jul, 5:00	0.508	03-Sep, 17:00	1.27
6-Jun, 12:00				01-Jul, 6:00				30-Jul, 6:00	0.254	03-Sep, 18:00	0.254
6-Jun, 13:00				01-Jul, 7:00	0.254			30-Jul, 7:00	0.508	03-Sep, 19:00	0.508
6-Jun, 14:00								30-Jul, 8:00		03-Sep, 20:00	
6-Jun, 15:00								30-Jul, 9:00		03-Sep, 21:00	
6-Jun, 16:00								30-Jul, 10:00	0.254	03-Sep, 22:00	3.048
6-Jun, 17:00	0.508							30-Jul, 11:00		03-Sep, 23:00	2.286
6-Jun, 18:00	0.254							30-Jul, 12:00		04-Sep, 0:00	
								30-Jul, 13:00	0.254	04-Sep, 1:00	
								30-Jul, 14:00	0.254	04-Sep, 2:00	
								30-Jul, 15:00	0.254	04-Sep, 3:00	0.762
								30-Jul, 16:00	0.508	04-Sep, 4:00	0.508
								30-Jul, 17:00	0.508	04-Sep, 5:00	0.254
								30-Jul, 18:00			
								30-Jul, 19:00	0.254		

Table 6.8 Results of statistical analysis on TDR data (volumetric moisture content, %) over specific precipitation events
✓ = statistically significant variation ($\alpha = 0.05$)

Date	June 5 - 7, 2002			June 29 - 30, 2002			July 1 - 2, 2002		
Probe	surface	above l	below l	surface	above l	below l	surface	above l	below l
Model	✓	✓	✓	✓	✓	✓	✓	✓	✓
R^2	0.985	0.999	0.999	0.965	0.999	0.999	0.998	0.999	0.999
mean	24.5	27.8	10.2	23.7	28.0	8.9	26.0	28.2	9.3
std dev	2.6	3.8	10.9	3.6	3.6	8.7	2.2	3.7	9.2
coef. var	10.5	13.5	106.7	15.3	13.0	98.7	8.5	13.0	98.3
stderr	0.09	0.13	0.67	0.16	0.15	0.36	0.10	0.15	0.38
nest	✓	✓	✓	✓	✓	✓	✓	✓	✓
day	✓	✓		✓			✓	✓	
LSMeans	1 28.4	3 33.0	3 42.8	1 28.7	3 33.1	3 34.8	1 29.3	3 33.1	3 36.7
(nest)	2 27.0	4 32.1	4 20.7	2 28.1	4 32.4	4 18.5	2 28.4	2 32.5	4 18.7
	6 25.4	2 31.8	8 12.0	5 25.9	2 32.3	8 8.8	9 28.3	4 32.4	2 9.9
↑	10 24.7	6 29.7	2 7.6	9 25.0	6 30.0	2 6.9	6 27.0	6 30.8	8 8.6
	5 24.7	8 29.4	1 6.1	6 23.8	1 29.4	1 5.9	5 26.9	1 29.4	5 5.9
	3 24.6	1 28.9	5 5.8	3 23.5	8 28.9	5 5.8	10 26.2	8 28.9	1 5.9
VMC	4 24.1	9 27.7	10 5.0	7 22.6	9 27.9	10 4.7	3 25.7	9 28.1	10 4.7
	9 23.9	11 26.9	12 4.7	11 21.9	11 26.2	12 4.6	11 25.5	11 26.3	12 4.7
	8 23.7	12 26.1	11 4.6	8 21.0	12 25.9	7 4.2	8 23.4	12 25.8	7 4.2
	11 21.8	10 23.9	9 4.6	10 20.4	10 25.1	9 4.2	7 23.2	5 25.7	11 4.2
	7 21.6	5 23.8	7 4.4	4 20.4	5 24.8	11 4.2	4 22.6	10 25.0	6 4.2
		7 19.8	6 3.8		7 20.2	6 3.7		7 20.1	9 4.2
Contrasts for. vs back	✓	✓	✓		✓	✓	✓	✓	✓
All nests significantly different except:	1 vs 2 2 vs 6 3 vs 4,5,6 3 vs 8,9,10 4 vs 5,6,8 4 vs 9,10 5vs6,8,9,10 6 vs 8,9,10 7 vs 11 8 vs 9,10 9 vs 10	5 vs 10	1 vs 5,10 5 vs 10,12 6 vs 7,9,10 6 vs 11,12 7 vs 9,10 7 vs 11,12 9 vs 10,11,12 10 vs 11,12 11 vs 12	1 vs 2 2 vs 5 3 vs 5,6,7 3 vs 8,9,11 4 vs 7,8 4 vs 10,11 5 vs 6,9 6 vs 7,9,11 7 vs 8,9 7 vs 10,11 8 vs 10,11 10 vs 11	2 vs 4 5 vs 10 11 vs 12	1 vs 5 6 vs 7,9,11 7 vs 9,11 7 vs 12 9 vs 11,12 10 vs 12 11 vs 12	1 vs 2,9 2 vs 9 3 vs 10,11 4 vs 7,8 5 vs 6,10 6 vs 10 7 vs 8 10 vs 11	2 vs 4 5 vs 12	1 vs 5 6 vs 7,9,10 6 vs 11,12 7 vs 9,10 7 vs 11,12 9 vs 11 10 vs 12
Notes:	12 is sig. diff. from all others	basically all sig. diff.		12 is sig. diff. from all others	basically all sig. diff.		12 is sig. diff. from all others	almost all signif. Different	

Table 6.8 (continued) Results of statistical analysis on TDR data (volumetric moisture content, %) over specific precipitation events

✓ = statistically significant variation ($\alpha = 0.05$)

Date	July 18 - 21, 2002			July 30 - August 1, 2002			September 2 - 5, 2002		
Probe	surface	above l	below l	surface	above l	below l	surface	above l	below l
Model	✓	✓	✓	✓	✓	✓	✓	✓	✓
R^2	0.977	0.998	0.999	0.997	0.999	0.999	0.993	0.999	0.999
mean	24.2	28.0	8.7	26.7	28.1	9.1	24.8	28.0	8.3
std dev	3.7	3.7	8.0	2.0	3.7	8.4	3.6	3.5	7.2
coef. var	15.2	13.2	92.5	7.4	13.2	92.8	14.4	12.6	86.2
stderr	0.11	0.11	0.24	0.07	0.13	0.29	0.11	0.10	0.21
nest	✓	✓	✓	✓	✓	✓	✓	✓	✓
day	✓	✓	✓	✓	✓		✓	✓	
LSMeans (nest)	2 28.5	3 33.1	3 32.3	9 29.3	3 33.1	3 33.9	2 28.8	3 32.8	3 29.0
	1 28.4	2 32.6	4 17.7	1 29.2	2 32.7	4 18.0	1 28.2	2 32.6	4 17.4
	9 26.1	4 32.2	2 9.2	2 28.6	4 32.2	2 10.4	9 27.1	4 31.9	2 8.9
VMC ↑	5 25.5	6 30.8	8 7.3	6 27.8	6 31.4	8 6.9	5 26.8	6 30.6	1 6.1
	6 24.4	1 29.7	5 5.9	5 27.5	1 30.2	5 6.2	6 26.6	1 29.8	8 6.1
	10 22.9	8 27.8	1 5.8	10 26.5	8 27.9	1 6.2	8 23.7	9 27.6	5 6.1
	3 22.6	9 27.7	10 4.6	3 25.7	9 27.5	6 5.2	11 23.2	8 27.2	6 4.7
	4 22.5	12 25.6	12 4.6	8 25.6	5 26.1	12 4.6	7 23.1	5 26.8	12 4.6
	8 22.0	11 25.6	6 4.6	11 25.4	11 25.7	10 4.5	3 22.4	11 26.0	10 4.4
	7 21.8	10 25.3	7 4.2	4 24.9	10 25.3	7 4.4	4 22.3	12 25.3	7 4.4
	11 21.3	5 25.2	11 4.1	7 23.1	12 25.1	11 4.2	10 20.8	10 25.1	11 4.3
		7 20.3	9 4.0		7 20.3	9 4.1		7 20.4	9 4.0
Contrasts for. vs back	✓	✓	✓	✓	✓	✓	✓	✓	✓
All nests significantly different except:	1 vs 2,9 2 vs 9 3 vs 4,6,7 3 vs 8,10,11 4 vs 6,7,8 4 vs 10,11 5 vs 6,8,10 6 vs7,8,9,10 7 vs 8,10,11 8 vs 10,11 10 vs 11	2 vs 3,4 5vs10,11,12 8 vs 9 10 vs 11,12 11 vs 12	1 vs 5 6 vs 7,9,10 6 vs 11,12 7 vs 9,10 7 vs 11,12 9 vs 10 9 vs 11,12 10 vs 11,12 11 vs 12	1 vs 2,9 2 vs 9 3 vs 4,8,11 4 vs 8,11 5 vs 6 8 vs 11		1 vs 5 6 vs 12 7 vs 9,10 7 vs 11,12 9 vs 10,11 9 vs 12 10 vs 11,12 11 vs 12	1 vs 2,5,6,9 2 vs 5,6,9 3 vs 4,7,8 3 vs 10,11 4 vs 7,8 4 vs 10,11 5 vs 6,9 6 vs 9 7 vs 8,10,11 8 vs 10,11 10 vs 11	2 vs 3,4 5 vs 8 8 vs 9 10 vs 12	1 vs 5,8 5 vs 8 6 vs 7,9,10 6 vs 11,12 7 vs 9,10 7 vs 11,12 9 vs 10 9 vs 11,12 10 vs 11,12 11 vs 12
Notes:	12 is sig. diff. from all others			12 is sig. diff. from all others	all signif. Different		12 is sig. diff. from all others		

Table 6.9 Electrical conductivity (dS m^{-1}) on July 24, 2001

Sampling Location (by access tube number)													
Depth (cm)	**1-1**	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**	**1-7**	**1-8**	**1-9**	**1-10**	**1-11**	**1-12**	**1-13**
0-20	0.7	0.4	0.4	0.5	0.7	0.8	0.5	0.5	0.4	0.9	0.4	0.5	1.8
20-40	0.5	0.6	0.7	0.7	1	1.6	0.5	0.6	0.4	1.1	0.7	0.7	0.8
40-60	0.6	0.7	2	0.7	1.5	2.5	0.5	0.6	0.5	0.6	0.5	1	0.7
60-80	1	1.5	2.9	0.7	1.6	2.7	0.6	0.9	0.6	0.4	0.4	0.5	1
80-100	1.3	1.4	1.2	0.5	1.6	2.4	0.4	0.5	0.4	0.3	0.4	0.4	1.3
100-120	1.1	1.2	0.6	1.1	2.1	1.9	0.4	0.4	0.3	0.4	0.5	0.5	1.5
120-140	1.4	1.5	0.7	1.6	2.4	2.9	0.4	0.3	0.3	0.4	0.5	0.5	0.6
140-160	1.5	1.5	0.7	2.1	2.6	2.8	0.4	0.3	0.4	0.4	0.3	0.9	1.7
Depth (cm)	**2-1**	**2-2**	**2-3**	**2-4**	**2-5**	**2-6**	**2-7**	**2-8**	**2-9**	**2-10**	**2-11**	**2-12**	**2-13**
0-20	1.0	0.5	0.8	0.5	0.4	0.9	0.6	0.5	0.5	0.4	0.5	0.5	0.6
20-40	1.1	0.7	1.9	0.6	0.4	0.9	0.7	1.1	0.5	0.4	0.4	0.5	0.8
40-60	1.1	1.3	2.3	0.4	0.4	1.4	0.7	1.5	0.5	0.4	0.4	0.4	1.2
60-80	0.9	0.9	3	0.4	0.3	2.1	0.7	2.4	0.6	0.4	0.3	0.4	1
80-100	0.8	0.5	0.5	0.2	0.2	1.2	0.7	0.9	0.4	0.3	0.3	0.3	1.7
100-120	0.5	0.5	0.5	0.3	0.3	1.9	0.5	0.6	0.4	0.3	0.3	0.3	1.9
120-140	0.6	0.6	0.4	0.3	0.8	2.6	0.4	0.5	0.3	0.3	0.3	0.3	1.9
140-160	0.7	0.7	0.4	0.6	1.9	2.5	0.5	0.6	0.3	0.3	0.2	0.4	2
Depth (cm)	**3-1**	**3-2**	**3-3**	**3-4**	**3-5**	**3-6**	**3-7**	**3-8**	**3-9**	**3-10**	**3-11**	**3-12**	**3-13**
0-20	1.2	0.7	0.8	0.5	0.6	0.5	1	0.7	0.5	0.4	0.4	0.8	0.5
20-40	1.6	1	0.8	0.4	1.6	0.5	1	0.6	0.8	0.4	0.5	0.5	0.5
40-60	2	1.8	1.2	0.4	0.7	0.7	1	0.5	0.8	0.3	0.6	0.5	0.8
60-80	1.9	1.5	1.5	0.7	1.1	1.3	1	0.5	0.5	0.3	0.4	0.3	1.2
80-100	2.1	0.5	0.5	0.6	2.5	1.8	0.6	0.4	0.4	0.3	0.3	0.2	1.4
100-120	0.7	0.6	0.5	0.6	2.3	2.4	0.6	0.4	0.4	0.2	0.3	0.2	1.6
120-140	0.6	1	0.6	1.1	2.2	1.9		0.5	0.4	0.3	0.3	0.3	1.9
140-160	0.6	1.8	1	2.3	2.5	1.8	0.6	0.5	0.3	0.3	0.4	0.5	2.2
Depth (cm)	**4-1**	**4-2**	**4-3**	**4-4**	**4-5**	**4-6**	**4-7**	**4-8**	**4-9**	**4-10**	**4-11**	**4-12**	**4-13**
0-20	0.8	0.6	0.6	0.5	0.5	1.1	0.7	0.6	1.7	0.8	0.7	0.6	0.9
20-40	1.7	0.5	0.8	0.8	0.9	1.7	0.7	0.7	2.5	0.8	0.8	0.8	1.1
40-60	2.6	1	1.6	0.9	2.3	2.8	0.7	1.2	2.3	0.8	0.9	0.7	1.2
60-80	3	1.6	1.8	1	3.3	2.4	0.9	1	3.3	0.6	0.4	0.3	1
80-100	2.4	0.8	0.9	0.6		2	0.4	0.6	4	0.4	0.5	0.3	1
100-120	1.8	0.9	0.8	0.6	1.9	2.2	0.4	0.5	3.8	0.5	0.5	0.3	1.2
120-140	1.9	1.9	1.1	0.9	2.7	2.5	0.4	0.4	3.3	0.5	0.5	0.5	1.8
140-160	2.1	2.3	1.9	1.8	2.1	2.5	0.4	0.5	2	0.5	0.5	0.3	1.7

Average across all transects													
Depth (cm)	**Tube 1**	**Tube 2**	**Tube 3**	**Tube 4**	**Tube 5**	**Tube 6**	**Tube 7**	**Tube 8**	**Tube 9**	**Tube 10**	**Tube 11**	**Tube 12**	**Tube 13**
0-20	0.9	0.6	0.7	0.5	0.6	0.8	0.7	0.6	0.8	0.6	0.5	0.6	1.0
20-40	1.2	0.7	1.1	0.6	1.0	1.2	0.7	0.8	1.1	0.7	0.6	0.6	0.8
40-60	1.6	1.2	1.8	0.6	1.2	1.9	0.7	1.0	1.0	0.5	0.6	0.7	1.0
60-80	1.7	1.4	2.3	0.7	1.6	2.1	0.8	1.2	1.3	0.4	0.4	0.4	1.1
80-100	1.7	0.8	0.8	0.5	1.4	1.9	0.5	0.6	1.3	0.3	0.4	0.3	1.4
100-120	1.0	0.8	0.6	0.7	1.7	2.1	0.5	0.5	1.2	0.4	0.4	0.3	1.6
120-140	1.1	1.3	0.7	1.0	2.0	2.5	0.4	0.4	1.1	0.4	0.4	0.4	1.6
140-160	1.2	1.6	1.0	1.7	2.3	2.4	0.5	0.5	0.8	0.4	0.4	0.5	1.9

Table 6.10 SAR on July 24, 2001

Sampling Location (by access tube number)													
Depth (cm)	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10	1-11	1-12	1-13
0-20	1	1.7	0.9	1.1	2.3	2.2	2	1.4	1.8	0.8	1.1	1.8	2.2
20-40	2.1	1.9	0.9	1.5	3.1	3.2	2.8	2.1	2	0.8	1.1	2.6	1.4
40-60	2.3	2.2	0.8	1.8	4.8	6	2	2.5	2	0.8	0.5	3.6	2.9
60-80	2.3	3.9	0.9	2.4	9.3	12.6	2.2	2.7	2.1	0.5	0.3	1.7	7.1
80-100	4.3	8.8	0.7	5.8	16	25.3	2.1	2.2	1.8	0.5	0.2	1.7	10.5
100-120	12.4	12.8	0.8	22.5	37.8	25.4	1.8	2	1.1	0.5	0.2	3	21.1
120-140	15.9	24	0.9	49	41.1	29	1.8	1.6	1.1	0.5	0.2	4.7	23.1
140-160	26.9	20.5	1.3	40.8	35.3	69.7	1.7	2.2	1.7	0.6	0.3	9.5	34.3
Depth (cm)	**2-1**	**2-2**	**2-3**	**2-4**	**2-5**	**2-6**	**2-7**	**2-8**	**2-9**	**2-10**	**2-11**	**2-12**	**2-13**
0-20	1.1	0.5	0.5	0.4	0.8	1.1	2.2	1.1	0.6	0.7	0.6	0.6	0.9
20-40	1.4	0.5	0.5	0.5	0.3	1.4	2.9	2.3	0.6	0.7	0.6	0.6	1.3
40-60	1.4	0.7	0.9	1	0.6	1.8	3.4	2.3	0.5	0.7	0.6	0.7	2.4
60-80	1.7	1.1	1.4	1.4	0.4	4.6	4	1.5	0.5	0.4	0.3	1.5	7.2
80-100	1.4	1.1	0.7	0.6	0.3	7.7	4.1	0.7	0.5	0.4	0.3	0.4	17.1
100-120	1.3	1.1	0.6	0.5	0.4	19.1	3	1.3	0.5	0.3	0.3	0.4	14.2
120-140	1.8	1.8	0.6	0.5	9.6	31.9	2.9	1.1	1	0.3	0.7	0.4	13.8
140-160	3.7	4.3	0.7	0.2	24.2	24.1	4.6	1.5	1.7	0.3	0.6	0.5	22.9
Depth (cm)	**3-1**	**3-2**	**3-3**	**3-4**	**3-5**	**3-6**	**3-7**	**3-8**	**3-9**	**3-10**	**3-11**	**3-12**	**3-13**
0-20	1.6	1.5	2.2	0.5	1.7	0.9	2.7	1.8	0.8	0.5	1.9	1.3	0.9
20-40	1.9	1.4	3.1	0.5	2.8	1.3	2.8	1.5	1	0.6	2	1.7	0.9
40-60	1.6	1.2	4.3	1	3.6	1.5	2.8	1.4	1	0.5	2	1.7	0.7
60-80	1.2	1.3	5.5	2.4	4.5	3.6	2.7	1.5	0.8	0.4	1.4	1	1.4
80-100	1.6	1.5	2.9	3.4	22.3	9.4	2.6	1.5	0.7	0.3	1.3	0.9	6.6
100-120	1.4	2.7	2.8	4.6	24.9	19.8	3.8	1.9	0.7	0.2	1.1	0.9	12.3
120-140	1.8	8.1	3.4	10.3	17.9	24.4		2.7	0.9	0.2	1	1.1	18.6
140-160	3.6	13.8	9.4	46.8	26.6	22.5	6.8	3	1.1	0.2	1.2	2.3	16.6
Depth (cm)	**4-1**	**4-2**	**4-3**	**4-4**	**4-5**	**4-6**	**4-7**	**4-8**	**4-9**	**4-10**	**4-11**	**4-12**	**4-13**
0-20	1.4	0.6	1.6	1.9	0.9	1.3	1.8	1.4	2	1.2	1	1.8	1.6
20-40	2.8	1.8	3.9	3	2.9	3	1.6	1.4	2.6	2.1	1.5	0.9	1.8
40-60	4.2	2.8	4.6	4.1	4.3	5.4	2	1.4	3	2.6	1	0.8	2.2
60-80	7.1	4.1	4.7	4.1	9.5	9.8	2.1	1.7	3.1	3.1	0.4	0.6	4.3
80-100	10.7	4.2	5.2	2.4		17	1.2	1.2	3.4	2.3	0.4	0.4	5
100-120	16	7.7	5.6	1.9	14.8	25.4	1.2	1	2.6	2.1	0.5	0.6	7
120-140	21.1	22.9	12.8	4.7	24.4	31.5	1	0.9	2	1.5	0.3	0.7	19.3
140-160	28.2	27.6	20.4	16.4	37.1	50	1	0.9	1.4	1.4	0.3	0.9	17.6

Average across all transects													
Depth (cm)	Tube 1	Tube 2	Tube 3	Tube 4	Tube 5	Tube 6	Tube 7	Tube 8	Tube 9	Tube 10	Tube 11	Tube 12	Tube 13
0-20	1.3	1.1	1.3	1.0	1.4	1.4	2.2	1.4	1.3	0.8	1.2	1.4	1.4
20-40	2.1	1.4	2.1	1.4	2.3	2.2	2.5	1.8	1.6	1.1	1.3	1.5	1.4
40-60	2.4	1.7	2.7	2.0	3.3	3.7	2.6	1.9	1.6	1.2	1.0	1.7	2.1
60-80	3.1	2.6	3.1	2.6	5.9	7.7	2.8	1.9	1.6	1.1	0.6	1.2	5.0
80-100	4.5	3.9	2.4	3.1	12.9	14.9	2.5	1.4	1.6	0.9	0.6	0.9	9.8
100-120	7.8	6.1	2.5	7.4	19.5	22.4	2.5	1.6	1.2	0.8	0.5	1.2	13.7
120-140	10.2	14.2	4.4	16.1	23.3	29.2	1.9	1.6	1.3	0.6	0.6	1.7	18.7
140-160	15.6	16.6	8.0	26.1	30.8	41.6	3.5	1.9	1.5	0.6	0.6	3.3	22.9

Table 6.11 Saturation percentage (%) on July 24, 2001

Sampling Location (by access tube number)													
Depth (cm)	**1-1**	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**	**1-7**	**1-8**	**1-9**	**1-10**	**1-11**	**1-12**	**1-13**
0-20	45	38	45	42	44	41	48	42	35	140	49	45	30
20-40	42	40	43	41	48	46	56	42	43	390	58	50	42
40-60	48	44	42	43	48	46	54	43	47	35	32	53	28
60-80	50	58	38	44	44	43	50	46	40	30	31	29	28
80-100	43	33	28	29	30	31	30	28	29	28	28	34	30
100-120	29	32	28	28	29	28	30	29	29	28	25	29	28
120-140	30	31	29	28	29	27	27	29	31	28	30	34	45
140-160	32	29	28	28	26	28	29	28	30	29	28	32	30
Depth (cm)	**2-1**	**2-2**	**2-3**	**2-4**	**2-5**	**2-6**	**2-7**	**2-8**	**2-9**	**2-10**	**2-11**	**2-12**	**2-13**
0-20	37	41	47	39	44	70	42	37	39	41	40	43	57
20-40	36	39	53	33	45	49	55	57	42	44	45	46	190
40-60	36	46	45	40	48	50	44	180	55	42	46	48	190
60-80	38	52	140	41	29	50	43	55	50	28	31	28	33
80-100	28	26	30	31	30	30	41	29	30	28	31	30	31
100-120	30	31	29	28	30	29	27	28	27	29	30	29	31
120-140	30	27	31	26	28	27	27	30	28	28	32	30	30
140-160	29	29	29	27	29	29	29	30	28	30	33	29	33
Depth (cm)	**3-1**	**3-2**	**3-3**	**3-4**	**3-5**	**3-6**	**3-7**	**3-8**	**3-9**	**3-10**	**3-11**	**3-12**	**3-13**
0-20	50	47	45	46	44	41	43	40	37	43	35	61	51
20-40	55	52	38	45	78	45	43	43	100	43	41	49	48
40-60	100	110	46	45	730	48	42	44	70	30	38	46	53
60-80	120	240	48	47	360	48	41	43	35	28	30	29	73
80-100	66	31	30	31	29	47	31	32	30	31	27	28	33
100-120	32	30	29	32	31	28	30	28	31	31	28	28	33
120-140	30	31	30	32	31	29		31	30	31	26	30	30
140-160	31	30	32	31	30	32	30	29	28	31	26	29	30
Depth (cm)	**4-1**	**4-2**	**4-3**	**4-4**	**4-5**	**4-6**	**4-7**	**4-8**	**4-9**	**4-10**	**4-11**	**4-12**	**4-13**
0-20	50	53	38	45	43	100	48	43	38	48	46	31	44
20-40	91	44	36	43	43	100	50	45	38	45	48	33	79
40-60	50	53	46	45	48	65	50	52	47	43	50	38	68
60-80	68	55	54	45	57	54	52	53	46	28	30	29	31
80-100	55	28	27	30		28	31	29	50	28	28	28	30
100-120	29	29	29	31	32	32	29	29	33	30	30	27	29
120-140	28	27	29	29	30	29	29	30	28	30	29	35	29
140-160	29	28	28	31	32	29	29	28	29	28	30	32	31
Average across all transects													
Depth (cm)	**Tube 1**	**Tube 2**	**Tube 3**	**Tube 4**	**Tube 5**	**Tube 6**	**Tube 7**	**Tube 8**	**Tube 9**	**Tube 10**	**Tube 11**	**Tube 12**	**Tube 13**
0-20	46	45	44	43	44	63	45	41	37	68	43	45	46
20-40	56	44	43	41	54	60	51	47	56	131	48	45	90
40-60	59	63	45	43	219	52	48	80	55	38	42	46	85
60-80	69	101	70	44	123	49	47	49	43	29	31	29	41
80-100	48	30	29	30	30	34	33	30	35	29	29	30	31
100-120	30	31	29	30	31	29	29	29	30	30	28	28	30
120-140	30	29	30	29	30	28	28	30	29	29	29	32	34
140-160	30	29	29	29	29	30	29	29	29	30	29	31	31

Table 6.12 Chloride concentration (mg/L) on July 24, 2001

Sampling Location (by access tube number)													
Depth (cm)	**1-1**	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**	**1-7**	**1-8**	**1-9**	**1-10**	**1-11**	**1-12**	**1-13**
0-20	8	18	11	14	29	80	13	14	9	13	13	17	322
20-40	10	11	9	14	66	254	9	10	9	11	20	58	85
40-60	12	25	10	22	149	497	9	7	8	5	8	127	81
60-80	45	103	15	56	191	550	10	7	11	4	5	51	155
80-100	136	163	7	64	320	482	7	6	6	4	3	30	220
100-120	129	155	6	191	388	348	6	4	3	3	3	36	252
120-140	186	220	5	284	442	560	6	5	4	4	3	46	58
140-160	222	214	14	378	488	515	8	4	6	4	3	141	342
Depth (cm)	**2-1**	**2-2**	**2-3**	**2-4**	**2-5**	**2-6**	**2-7**	**2-8**	**2-9**	**2-10**	**2-11**	**2-12**	**2-13**
0-20	18	8	5	18	9	17	40	10	11	14	8	15	30
20-40	20	6	<1	14	7	34	16	2	9	12	6	15	72
40-60	6	<1	<1	8	10	96	15	<1	3	12	4	14	108
60-80	6	3	<1	7	5	344	16	<1	3	5	2	8	152
80-100	54	4	<1	3	3	240	14	<1	2	4	2	5	272
100-120	13	5	<1	8	6	438	8	<1	3	4	3	5	324
120-140	25	24	<1	3	143	560	7	<1	3	3	3	3	316
140-160	52	60	<1	10	366	451	8	<1	3	2	2	9	320
Depth (cm)	**3-1**	**3-2**	**3-3**	**3-4**	**3-5**	**3-6**	**3-7**	**3-8**	**3-9**	**3-10**	**3-11**	**3-12**	**3-13**
0-20	29	45	18	16	39	14	41	41	8	5	13	24	19
20-40	24	32	15	7	136	22	36	24	7	5	16	15	20
40-60	35	11	16	6	96	54	24	14	13	3	17	16	32
60-80	7	15	15	70	137	240	19	7	9	4	7	7	150
80-100	79	23	6	60	412	374	8	6	8	2	6	6	136
100-120	22	49	12	57	409	550	10	5	8	3	6	6	310
120-140	29	134	35	171	408	348		5	6	3	5	7	372
140-160	57	244	112	376	406	324	9	4	5	3	6	51	440
Depth (cm)	**4-1**	**4-2**	**4-3**	**4-4**	**4-5**	**4-6**	**4-7**	**4-8**	**4-9**	**4-10**	**4-11**	**4-12**	**4-13**
0-20	33	14	20	13	11	67	39	16	20	29	16	84	77
20-40	80	13	21	10	35	145	21	14	30	28	14	43	104
40-60	204	28	57	13	103	292	12	19	21	25	10	21	102
60-80	367	74	115	19	317	338	11	12	13	16	3	6	118
80-100	310	63	64	11		388	4	10	6	7	3	4	129
100-120	264	106	72	11	318	430	5	5	6	8	3	3	162
120-140	304	276	139	65	429	427	4	5	5	8	4	12	266
140-160	314	336	304	272	326	389	5	5	4	9	2	15	286
Average across all transects													
Depth (cm)	**Tube 1**	**Tube 2**	**Tube 3**	**Tube 4**	**Tube 5**	**Tube 6**	**Tube 7**	**Tube 8**	**Tube 9**	**Tube 10**	**Tube 11**	**Tube 12**	**Tube 13**
0-20	22	21	14	15	22	45	33	20	12	15	13	35	112
20-40	34	16	15	11	61	114	21	13	14	14	14	33	70
40-60	64	21	28	12	90	235	15	13	11	11	10	45	81
60-80	106	49	48	38	163	368	14	9	9	7	4	18	144
80-100	145	63	26	35	245	371	8	7	6	4	4	11	189
100-120	107	79	30	67	280	442	7	5	5	5	4	13	262
120-140	136	164	60	131	356	474	6	5	5	5	4	17	253
140-160	161	214	143	259	397	420	8	4	5	5	3	54	347

Table 6.13 Sodium concentration (mg/L) on July 24, 2001

Sampling Location (by access tube number)													
Depth (cm)	**1-1**	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**	**1-7**	**1-8**	**1-9**	**1-10**	**1-11**	**1-12**	**1-13**
0-20	43	46	28	35	80	84	56	46	49	43	34	53	404
20-40	58	61	38	60	119	167	80	66	54	46	46	84	59
40-60	73	81	66	65	214	355	60	80	59	29	18	134	90
60-80	101	204	100	78	296	535	71	109	67	15	9	48	180
80-100	188	269	40	99	358	545	54	64	47	14	7	38	254
100-120	233	248	32	249	482	454	45	43	25	15	8	66	321
120-140	303	366	37	384	558	685	44	38	23	16	8	89	77
140-160	352	348	48	512	640	700	43	42	39	16	7	184	400
Depth (cm)	**2-1**	**2-2**	**2-3**	**2-4**	**2-5**	**2-6**	**2-7**	**2-8**	**2-9**	**2-10**	**2-11**	**2-12**	**2-13**
0-20	57	19	24	15	25	53	69	39	23	25	24	23	36
20-40	78	24	45	21	11	64	97	115	21	22	19	23	56
40-60	72	48	90	32	21	107	114	141	19	23	21	22	122
60-80	73	55	149	42	12	278	115	141	21	14	8	39	189
80-100	57	37	27	14	8	228	122	37	16	10	7	10	323
100-120	43	33	24	13	11	412	76	46	17	8	9	12	360
120-140	60	55	19	15	178	605	66	36	27	7	18	10	366
140-160	101	117	19	9	430	585	89	50	41	8	12	15	407
Depth (cm)	**3-1**	**3-2**	**3-3**	**3-4**	**3-5**	**3-6**	**3-7**	**3-8**	**3-9**	**3-10**	**3-11**	**3-12**	**3-13**
0-20	83	59	87	18	62	31	109	68	26	18	53	58	20
20-40	119	69	109	16	158	41	116	52	45	20	58	54	21
40-60	124	91	168	27	106	55	116	43	44	14	62	54	22
60-80	90	88	240	80	161	156	112	43	30	11	35	24	51
80-100	122	46	75	83	542	326	75	40	23	7	31	20	236
100-120	54	68	69	99	502	540	99	49	22	4	28	17	306
120-140	55	179	80	219	460	428		66	24	5	22	26	406
140-160	92	331	187	546	556	416	124	67	27	5	31	59	450
Depth (cm)	**4-1**	**4-2**	**4-3**	**4-4**	**4-5**	**4-6**	**4-7**	**4-8**	**4-9**	**4-10**	**4-11**	**4-12**	**4-13**
0-20	60	26	55	58	31	68	64	48	132	53	42	66	75
20-40	178	58	125	112	116	178	64	58	214	81	64	42	91
40-60	305	116	224	135	296	393	74	79	224	97	47	34	112
60-80	472	214	258	158	615	436	87	80	315	82	13	16	148
80-100	470	124	149	71		434	32	44	379	51	15	11	161
100-120	412	179	141	57	404	500	32	30	290	54	16	13	213
120-140	462	444	232	141	635	605	25	26	211	43	11	25	384
140-160	494	546	436	392	504	610	29	27	108	43	11	22	364
Average across all transects													
Depth (cm)	**Tube 1**	**Tube 2**	**Tube 3**	**Tube 4**	**Tube 5**	**Tube 6**	**Tube 7**	**Tube 8**	**Tube 9**	**Tube 10**	**Tube 11**	**Tube 12**	**Tube 13**
0-20	61	38	49	32	50	59	75	50	58	35	38	50	134
20-40	108	53	79	52	101	113	89	73	84	42	47	51	57
40-60	144	84	137	65	159	228	91	86	87	41	37	61	87
60-80	184	140	187	90	271	351	96	93	108	31	16	32	142
80-100	209	119	73	67	303	383	71	46	116	21	15	20	244
100-120	186	132	67	105	350	477	63	42	89	20	15	27	300
120-140	220	261	92	190	458	581	45	42	71	18	15	38	308
140-160	260	336	173	365	533	578	71	47	54	18	15	70	405

Table 6.14 Calcium concentration (mg/L) on July 24, 2001

Sampling Location (by access tube number)													
Depth (cm)	**1-1**	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**	**1-7**	**1-8**	**1-9**	**1-10**	**1-11**	**1-12**	**1-13**
0-20	96	39	54	63	64	84	43	60	37	143	46	47	15
20-40	41	58	104	86	84	163	40	56	39	167	89	59	90
40-60	59	77	410	74	92	202	44	59	45	73	78	75	52
60-80	110	152	635	61	57	104	50	88	57	36	62	43	32
80-100	105	41	209	14	28	27	35	45	36	30	51	25	28
100-120	17	17	80	6	9	16	32	26	21	35	63	24	11
120-140	16	11	84	3	9	29	28	24	20	35	60	19	63
140-160	8	12	74	7	15	6	26	15	26	36	33	20	7
Depth (cm)	**2-1**	**2-2**	**2-3**	**2-4**	**2-5**	**2-6**	**2-7**	**2-8**	**2-9**	**2-10**	**2-11**	**2-12**	**2-13**
0-20	151	73	143	59	38	136	59	74	48	37	71	68	89
20-40	167	104	436	84	75	122	53	140	65	51	58	68	93
40-60	166	271	492	49	36	197	63	206	81	62	60	58	146
60-80	115	120	615	50	42	206	45	486	77	47	36	34	36
80-100	80	54	73	29	33	48	47	149	61	34	28	40	17
100-120	56	40	67	25	29	27	33	64	53	26	30	33	27
120-140	57	41	44	37	16	19	27	53	30	34	24	34	27
140-160	36	27	35	95	14	28	17	51	23	35	18	38	14
Depth (cm)	**3-1**	**3-2**	**3-3**	**3-4**	**3-5**	**3-6**	**3-7**	**3-8**	**3-9**	**3-10**	**3-11**	**3-12**	**3-13**
0-20	151	69	83	86	74	47	94	89	68	70	43	115	27
20-40	212	114	67	58	180	54	101	71	100	65	46	54	18
40-60	318	284	82	43	43	69	103	54	104	47	52	59	58
60-80	289	235	96	57	64	98	93	55	75	49	34	27	82
80-100	315	38	34	32	20	64	37	42	48	33	30	24	60
100-120	84	24	27	25	16	38	31	37	49	26	32	16	32
120-140	48	17	24	23	32	15		29	35	29	25	28	23
140-160	31	22	17	7	20	16	12	24	30	36	31	33	16
Depth (cm)	**4-1**	**4-2**	**4-3**	**4-4**	**4-5**	**4-6**	**4-7**	**4-8**	**4-9**	**4-10**	**4-11**	**4-12**	**4-13**
0-20	96	85	67	52	71	154	77	72	246	101	97	50	117
20-40	202	54	55	73	94	199	85	97	408	84	97	105	142
40-60	261	91	127	64	274	300	82	186	328	74	122	98	142
60-80	227	142	154	72	242	108	93	135	585	37	49	37	62
80-100	101	40	40	49		36	35	62	595	23	63	28	49
100-120	34	23	30	50	40	21	32	45	610	28	55	22	48
120-140	23	17	15	44	33	18	31	40	585	32	50	70	20
140-160	15	18	23	27	9	8	37	45	334	37	49	25	21

Average across all transects													
Depth (cm)	**Tube 1**	**Tube 2**	**Tube 3**	**Tube 4**	**Tube 5**	**Tube 6**	**Tube 7**	**Tube 8**	**Tube 9**	**Tube 10**	**Tube 11**	**Tube 12**	**Tube 13**
0-20	124	67	87	65	62	105	68	74	100	88	64	70	62
20-40	156	83	166	75	108	135	70	91	153	92	73	72	86
40-60	201	181	278	58	111	192	73	126	140	64	78	73	100
60-80	185	162	375	60	101	129	70	191	199	42	45	35	53
80-100	150	43	89	31	27	44	39	75	185	30	43	29	39
100-120	48	26	51	27	24	26	32	43	183	29	45	24	30
120-140	36	22	42	27	23	20	29	37	168	33	40	38	33
140-160	23	20	37	34	15	15	23	34	103	36	33	29	15

Table 6.15 Magnesium concentration (mg/L) on July 24, 2001

Sampling Location (by access tube number)													
Depth (cm)	**1-1**	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**	**1-7**	**1-8**	**1-9**	**1-10**	**1-11**	**1-12**	**1-13**
0-20	23	9	11	12	17	18	11	14	10	35	17	12	5
20-40	9	14	21	23	17	30	13	13	9	54	22	14	24
40-60	12	15	71	15	36	37	14	13	11	20	22	18	14
60-80	23	31	132	11	12	20	18	20	12	13	19	11	10
80-100	24	18	37	5	6	5	9	13	9	13	19	9	10
100-120	6	7	18	2	2	5	8	6	9	18	25	7	4
120-140	7	4	22	1	3	8	10	10	7	20	21	5	17
140-160	3	6	21	3	6	1	12	7	9	17	14	5	2
Depth (cm)	**2-1**	**2-2**	**2-3**	**2-4**	**2-5**	**2-6**	**2-7**	**2-8**	**2-9**	**2-10**	**2-11**	**2-12**	**2-13**
0-20	29.0	19	42	25	19	32	11	17	33	29	20	24	22
20-40	32.0	26	102	32	17	28	21	28	22	19	15	17	26
40-60	28	72	119	21	31	40	12	46	18	16	14	17	35
60-80	20	43	179	13	13	43	10	87	31	16	10	11	10
80-100	28	20	26	9	7	11	13	28	20	14	13	13	6
100-120	14	20	24	15	12	5	9	17	16	19	14	18	13
120-140	17	20	17	14	6	5	8	15	16	12	13	11	16
140-160	13	17	15	25	6	10	7	22	12	12	9	13	6
Depth (cm)	**3-1**	**3-2**	**3-3**	**3-4**	**3-5**	**3-6**	**3-7**	**3-8**	**3-9**	**3-10**	**3-11**	**3-12**	**3-13**
0-20	38	29	20	17	15	21	19	13	11	16	10	28	6
20-40	57	39	16	13	41	16	18	9	25	15	9	13	14
40-60	88	79	22	11	13	18	18	8	30	11	12	13	12
60-80	83	66	28	16	19	27	20	7	15	12	10	8	15
80-100	81	21	10	8	15	16	15	9	18	11	10	7	23
100-120	20	15	11	6	9	11	12	8	13	8	10	6	9
120-140	14	12	11	7	11	5		10	14	11	8	9	8
140-160	11	13	8	2	8	6	8	9	11	15	13	10	24
Depth (cm)	**4-1**	**4-2**	**4-3**	**4-4**	**4-5**	**4-6**	**4-7**	**4-8**	**4-9**	**4-10**	**4-11**	**4-12**	**4-13**
0-20	24	26	16	13	17	40	13	14	48	27	30	29	24
20-40	57	14	15	18	17	46	19	17	72	17	27	33	32
40-60	83	25	33	12	47	61	16	35	56	17	30	30	29
60-80	68	42	44	23	45	25	19	22	108	9	12	12	16
80-100	28	16	13	11		8	9	20	217	8	19	12	17
100-120	10	11	11	11	10	5	12	18	203	14	22	11	14
120-140	8	7	6	14	11	6	11	16	163	16	25	22	6
140-160	5	7	7	10	3	2	16	16	77	19	29	12	7

Average across all transects													
Depth (cm)	**Tube 1**	**Tube 2**	**Tube 3**	**Tube 4**	**Tube 5**	**Tube 6**	**Tube 7**	**Tube 8**	**Tube 9**	**Tube 10**	**Tube 11**	**Tube 12**	**Tube 13**
0-20	29	21	22	17	17	28	14	15	26	27	19	23	14
20-40	39	23	39	22	23	30	18	17	32	26	18	19	24
40-60	53	48	61	15	32	39	15	26	29	16	20	20	23
60-80	49	46	96	16	22	29	17	34	42	13	13	11	13
80-100	40	19	22	8	9	10	12	18	66	12	15	10	14
100-120	13	13	16	9	8	7	10	12	60	15	18	11	10
120-140	12	11	14	9	8	6	10	13	50	15	17	12	12
140-160	8	11	13	10	6	5	11	14	27	16	16	10	10

Table 6.16 Nitrate concentration (mg/Kg) on July 24, 2001

Sampling Location (by access tube number)													
Depth (cm)	**1-1**	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**	**1-7**	**1-8**	**1-9**	**1-10**	**1-11**	**1-12**	**1-13**
0-20	1.4	1.6	0.8	1.6	2.4	1.6	1.6	1.2	1.4	2.3	1.6	2.2	1.4
20-40	1.6	1.4	2.0	1.2	1.8	1.2	1.8	1.6	2.2	5.8	1.2	2.0	1.4
40-60	1.6	1.2	1.0	1.2	1.6	1.2	2.2	1.2	2.2	1.4	1.2	2.0	1.2
60-80	1.6	1.4	1.0	1.4	2.0	2.2	1.6	2.0	1.8	1.2	1.4	1.0	1.8
80-100	1.4	1.6	1.2	1.2	1.2	1.6	1.0	1.6	1.0	1.0	1.4	1.0	1.0
100-120	1.4	1.2	1.0	1.8	1.6	1.6	1.2	1.4	1.2	1.0	0.8	1.0	1.2
120-140	1.6	1.2	1.0	1.0	1.6	2.0	1.0	1.2	1.0	0.8	1.0	1.0	1.4
140-160	1.2	1.2	1.0	1.8	1.4	2.0	1.0	1.2	1.0	1.2	1.0	1.4	1.4
Depth (cm)	**2-1**	**2-2**	**2-3**	**2-4**	**2-5**	**2-6**	**2-7**	**2-8**	**2-9**	**2-10**	**2-11**	**2-12**	**2-13**
0-20	1.0	1.0	0.8	0.8	0.6	1.2	0.6	1.0	1.0	1.0	0.8	0.8	1.0
20-40	0.8	0.6	0.6	0.8	0.4	1.2	0.8	0.6	0.8	0.8	0.6	0.8	2.5
40-60	0.6	0.6	0.6	0.6	0.8	1.2	0.8	0.6	1.0	1.2	0.8	0.8	4.0
60-80	0.6	0.8	1.6	0.6	0.4	1.2	1.4	0.6	0.8	0.8	0.6	0.6	0.8
80-100	0.6	0.6	0.6	0.4	0.6	1.0	1.0	0.8	0.8	0.8	0.6	0.8	0.8
100-120	0.4	0.6	0.6	0.6	0.6	1.0	0.6	0.8	1.0	0.6	0.6	0.6	0.6
120-140	0.4	0.6	0.4	0.4	0.4	1.0	0.8	0.6	0.6	0.6	0.6	0.6	0.6
140-160	0.6	0.6	0.6	0.4	0.6	1.8	1.0	0.8	0.6	0.8	0.6	0.6	1.0
Depth (cm)	**3-1**	**3-2**	**3-3**	**3-4**	**3-5**	**3-6**	**3-7**	**3-8**	**3-9**	**3-10**	**3-11**	**3-12**	**3-13**
0-20	0.8	1.4	0.8	0.8	0.8	1.0	0.6	2.4	2.2	2.2	2.0	2.4	3.6
20-40	0.8	1.0	0.8	0.6	1.0	0.8	0.8	1.8	2.0	2.2	1.6	2.0	2.0
40-60	1.7	1.3	1.0	0.6	3.0	0.6	0.6	2.2	2.0	2.0	2.2	2.4	1.8
60-80	1.3	3.0	0.8	0.8	3.3	0.8	0.6	2.4	1.4	1.6	1.8	2.0	1.6
80-100	0.8	0.6	0.6	0.6	1.2	1.2	0.4	2.4	1.4	1.6	1.6	1.4	1.2
100-120	0.6	0.6	0.6	0.6	1.0	1.0	0.6	1.6	1.4	1.2	1.4	1.4	2.0
120-140	0.6	0.6	0.6	0.4	1.0	1.6		1.2	1.8	1.2	1.2	1.8	1.2
140-160	0.6	0.6	0.4	0.8	1.0	1.0	0.6	1.0	1.4	1.2	1.4	1.4	1.4
Depth (cm)	**4-1**	**4-2**	**4-3**	**4-4**	**4-5**	**4-6**	**4-7**	**4-8**	**4-9**	**4-10**	**4-11**	**4-12**	**4-13**
0-20	1.4	1.6	2.4	2.0	2.4	7.5	2.0	1.0	2.4	2.8	2.2	1.8	3.8
20-40	1.4	2.2	1.8	2.2	1.8	7.9	1.6	2.0	2.2	3.6	2.2	2.6	3.4
40-60	1.4	1.4	2.2	3.0	2.0	2.6	1.6	1.4	2.2	2.4	2.0	2.0	3.0
60-80	2.8	1.6	2.4	1.8	1.8	3.0	1.8	2.0	2.2	2.0	2.0	2.6	2.8
80-100	1.6	1.2	0.8	1.6	3.5	1.6	1.6	2.2	1.8	1.8	2.2	2.0	0.8
100-120	1.8	1.8	1.6	2.0	1.8	2.0	1.8	2.0	1.2	2.4	1.8	2.0	1.0
120-140	1.6	2.2	1.8	1.6	1.6	1.8	1.4	2.2	1.6	2.0	1.4	4.4	1.0
140-160	2.6	2.0	2.0	1.8	2.0	1.8	1.6	2.2	1.8	1.6	1.2	2.6	1.4
Average across all transects													
Depth (cm)	**Tube 1**	**Tube 2**	**Tube 3**	**Tube 4**	**Tube 5**	**Tube 6**	**Tube 7**	**Tube 8**	**Tube 9**	**Tube 10**	**Tube 11**	**Tube 12**	**Tube 13**
0-20	1.2	1.4	1.2	1.3	1.6	2.8	1.2	1.4	1.8	2.1	1.7	1.8	2.5
20-40	1.2	1.3	1.3	1.2	1.3	2.8	1.3	1.5	1.8	3.1	1.4	1.9	2.3
40-60	1.3	1.1	1.2	1.4	1.9	1.4	1.3	1.4	1.9	1.8	1.6	1.8	2.5
60-80	1.6	1.7	1.5	1.2	1.9	1.8	1.4	1.8	1.6	1.4	1.5	1.6	1.8
80-100	1.1	1.0	0.8	1.0	1.6	1.4	1.0	1.8	1.3	1.3	1.5	1.3	1.0
100-120	1.1	1.1	1.0	1.3	1.3	1.4	1.1	1.5	1.2	1.3	1.2	1.3	1.2
120-140	1.1	1.2	1.0	0.9	1.2	1.6	1.1	1.3	1.3	1.2	1.1	2.0	1.1
140-160	1.3	1.1	1.0	1.2	1.3	1.7	1.1	1.3	1.2	1.2	1.1	1.5	1.3

Table 6.17 Potassium concentration (mg/L) on July 24, 2001

Sampling Location (by access tube number)													
Depth (cm)	1-1	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9	1-10	1-11	1-12	1-13
0-20	3	5	6	4	4	8	2	4	2	3	2	2	7
20-40	3	4	6	5	4	5	3	3	2	4	2	1	4
40-60	2	3	14	3	5	5	2	4	3	6	2	1	3
60-80	3	4	28	3	3	4	3	4	2	6	4	2	5
80-100	4	6	11	2	4	3	3	4	3	6	4	2	6
100-120	5	9	7	3	4	3	3	4	3	7	4	4	7
120-140	8	7	9	4	4	3	5	6	5	7	4	3	3
140-160	6	7	8	4	5	3	5	6	4	6	6	3	5
Depth (cm)	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10	2-11	2-12	2-13
0-20	5	4	6	7	8	4	4	8	6	3	2	3	2
20-40	5	4	6	3	5	3	3	6	5	2	1	2	2
40-60	7	4	6	2	3	5	3	5	3	2	2	2	3
60-80	7	2	5	3	4	5	2	9	4	4	3	3	3
80-100	19	2	5	3	3	3	3	5	4	4	5	4	5
100-120	5	5	6	5	3	5	5	6	5	5	5	6	5
120-140	8	8	7	5	4	7	8	7	6	7	7	5	6
140-160	8	7	7	9	6	7	7	10	7	7	5	6	6
Depth (cm)	3-1	3-2	3-3	3-4	3-5	3-6	3-7	3-8	3-9	3-10	3-11	3-12	3-13
0-20	3	2	4	5	2	3	5	3	4	2	1	2	1
20-40	4	1	2	3	4	3	5	3	14	1	1	1	1
40-60	3	4	1	3	1	4	6	4	4	1	1	1	1
60-80	3	4	4	3	2	5	5	3	4	2	2	2	1
80-100	4	3	5	3	4	3	6	3	6	8	3	3	3
100-120	6	5	6	3	8	3	7	5	6	4	3	4	2
120-140	4	7	9	4	5	3		6	6	5	3	2	3
140-160	4	7	6	3	5	3	5	7	6	6	5	4	4
Depth (cm)	4-1	4-2	4-3	4-4	4-5	4-6	4-7	4-8	4-9	4-10	4-11	4-12	4-13
0-20	5	5	5	4	8	18	7	5	8	7	3	12	4
20-40	2	2	2	4	4	10	4	3	8	5	5	2	3
40-60	4	2	2	4	6	5	5	4	6	3	1	1	3
60-80	3	2	3	4	7	6	5	4	9	4	3	2	4
80-100	2	3	4	4		4	5	7	28	6	4	5	8
100-120	4	4	7	5	5	5	6	8	33	10	7	6	8
120-140	5	6	7	7	9	5	7	9	27	10	8	2	8
140-160	7	6	5	7	8	5	10	8	18	12	10	3	6
Average across all transects													
Depth (cm)	Tube 1	Tube 2	Tube 3	Tube 4	Tube 5	Tube 6	Tube 7	Tube 8	Tube 9	Tube 10	Tube 11	Tube 12	Tube 13
0-20	4	4	5	5	6	8	5	5	5	4	2	5	4
20-40	4	3	4	4	4	5	4	4	7	3	2	2	3
40-60	4	3	6	3	4	5	4	4	4	3	2	1	3
60-80	4	3	10	3	4	5	4	5	5	4	3	2	3
80-100	7	4	6	3	4	3	4	5	10	6	4	4	6
100-120	5	6	7	4	5	4	5	6	12	7	5	5	6
120-140	6	7	8	5	6	5	7	7	11	7	6	3	5
140-160	6	7	7	6	6	5	7	8	9	8	7	4	5

Table 6.18 Sulphate concentration (mg/L) on July 24, 2001

Sampling Location (by access tube number)													
Depth (cm)	**1-1**	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**	**1-7**	**1-8**	**1-9**	**1-10**	**1-11**	**1-12**	**1-13**
0-20	154	39	55	76	85	108	30	38	23	207	39	57	230
20-40	71	135	196	224	245	284	53	107	31	533	110	97	134
40-60	131	214	1200	187	400	489	98	166	66	216	123	132	83
60-80	277	478	1890	130	326	451	122	232	132	115	102	47	122
80-100	338	278	607	52	218	316	59	103	68	103	108	38	163
100-120	165	181	237	109	266	262	53	58	32	128	149	76	186
120-140	270	268	259	210	354	400	54	50	36	131	139	71	106
140-160	234	242	232	282	353	353	52	48	58	100	61	106	220
Depth (cm)	**2-1**	**2-2**	**2-3**	**2-4**	**2-5**	**2-6**	**2-7**	**2-8**	**2-9**	**2-10**	**2-11**	**2-12**	**2-13**
0-20	360	66	170	47	86	159	61	71	81	45	30	62	43
20-40	438	168	920	47	21	247	101	386	90	55	46	48	111
40-60	491	485	1320	48	44	464	188	504	128	71	89	64	200
60-80	362	358	1920	56	27	472	179	1500	163	59	28	51	181
80-100	203	175	227	21	25	164	207	393	100	44	32	42	272
100-120	116	135	221	28	40	212	97	209	71	39	41	51	290
120-140	142	165	137	51	101	296	64	174	66	34	54	42	304
140-160	141	185	114	33	199	324	78	194	54	51	30	60	332
Depth (cm)	**3-1**	**3-2**	**3-3**	**3-4**	**3-5**	**3-6**	**3-7**	**3-8**	**3-9**	**3-10**	**3-11**	**3-12**	**3-13**
0-20	372	54	188	92	128	45	305	170	63	14	43	72	71
20-40	531	265	201	51	292	74	349	137	59	19	88	61	105
40-60	862	791	398	48	121	99	356	85	143	16	119	77	125
60-80	913	774	597	98	147	182	335	89	102	21	54	30	208
80-100	841	132	99	64	283	236	130	65	86	19	55	22	104
100-120	185	118	97	87	268	302	135	69	81	10	50	20	190
120-140	116	159	100	157	191	246		93	53	33	41	28	208
140-160	109	332	159	227	312	210	103	94	53	42	65	67	207
Depth (cm)	**4-1**	**4-2**	**4-3**	**4-4**	**4-5**	**4-6**	**4-7**	**4-8**	**4-9**	**4-10**	**4-11**	**4-12**	**4-13**
0-20	156	35	92	63	27	263	105	127	790	149	121	140	199
20-40	472	84	212	255	296	510	176	231	1430	176	215	143	203
40-60	1010	236	570	269	1110	790	225	508	1170	230	273	155	216
60-80	840	522	606	360	1230	482	296	399	2150	111	63	57	177
80-100	590	173	163	149		310	65	181	2420	51	126	59	194
100-120	302	153	135	163	346	348	72	133	2240	58	155	45	224
120-140	262	362	150	237	635	377	67	111	2050	76	160	43	300
140-160	306	382	238	366	332	352	107	129	1100	113	197	53	238

Average across all transects													
Depth (cm)	**Tube 1**	**Tube 2**	**Tube 3**	**Tube 4**	**Tube 5**	**Tube 6**	**Tube 7**	**Tube 8**	**Tube 9**	**Tube 10**	**Tube 11**	**Tube 12**	**Tube 13**
0-20	261	49	126	70	82	144	125	102	239	104	58	83	136
20-40	378	163	382	144	214	279	170	215	403	196	115	87	138
40-60	624	432	872	138	419	461	217	316	377	133	151	107	156
60-80	598	533	1253	161	433	397	233	555	637	77	62	46	172
80-100	493	190	274	72	175	257	115	186	669	54	80	40	183
100-120	192	147	173	97	230	281	89	117	606	59	99	48	223
120-140	198	239	162	164	320	330	62	107	551	69	99	46	230
140-160	198	285	186	227	299	310	85	116	316	77	88	72	249

Table 6.19 pH on July 24, 2001

Sampling Location (by access tube number)													
Depth (cm)	**1-1**	**1-2**	**1-3**	**1-4**	**1-5**	**1-6**	**1-7**	**1-8**	**1-9**	**1-10**	**1-11**	**1-12**	**1-13**
0-20	7.3	7.6	7.6	7.6	7.5	7.6	7.3	7.5	7.6	6.4	7.4	7.6	8.5
20-40	7.6	7.6	7.4	7.6	7.6	7.5	7.1	7.6	7.6	5.4	7.2	7.6	7.5
40-60	7.5	7.6	7.3	7.6	7.5	7.5	7.4	7.7	7.5	6.5	7.5	7.4	7.6
60-80	7.4	7.3	7.3	7.6	7.8	7.7	7.5	7.3	7.5	6.9	7.4	7.9	8
80-100	7.5	7.7	7.6	8.3	8.3	8.2	7.8	7.6	7.8	7	7.4	7.8	8.3
100-120	8	8.2	8	8.9	9	9.4	7.9	7.9	7.9	7.5	7.4	7.8	8.5
120-140	8.3	8.4	8.1	8.9	9	8.9	7.8	7.8	7.9	7.4	7.4	8	7.9
140-160	8.7	8.6	7.9	9	9	8.9	7.9	8.1	7.9	7.6	7.6	8.1	8.6
Depth (cm)	**2-1**	**2-2**	**2-3**	**2-4**	**2-5**	**2-6**	**2-7**	**2-8**	**2-9**	**2-10**	**2-11**	**2-12**	**2-13**
0-20	7.8	7.6	7.3	7.6	7.5	7	7.7	7.6	7.7	7.7	7.6	7.7	7.3
20-40	7.4	7.3	6.9	7.1	7.6	7.4	7.6	7.3	7.6	7.7	7.7	7.5	6.4
40-60	7.7	6.9	6.8	7.5	7.6	7.3	7.8	6.7	7.6	7.7	7.8	7.8	7
60-80	7.7	7.3	6	7.7	7.8	7.3	7.8	7.1	7.6	7.8	8	8	7.2
80-100	7.8	7.6	6.6	8	8	7.9	7.9	7.4	7.7	8	7.8	8	8
100-120	7.8	7.4	6.6	8	7.9	8.5	8	7.6	7.8	8	8.1	7.8	8.4
120-140	7.8	7.5	7.2	8	8.3	8.9	8.1	7.7	7.9	7.9	7.8	8.1	8.6
140-160	7.9	7.7	7.4	8	8.9	9.4	8.2	7.7	8	7.9	7.9	8.1	8.5
Depth (cm)	**3-1**	**3-2**	**3-3**	**3-4**	**3-5**	**3-6**	**3-7**	**3-8**	**3-9**	**3-10**	**3-11**	**3-12**	**3-13**
0-20	7.4	7.4	7.7	7.7	7.7	7.7	7.7	7.7	7.6	7.5	7.6	6.8	7.8
20-40	6.9	7.2	7.8	7.8	6.8	7.6	7.6	7.6	6.8	7.4	7.6	7.3	7.7
40-60	6.6	6.6	7.9	7.9	5.9	7.6	7.7	7.7	7.1	7.8	7.6	7.4	7.2
60-80	6.2	5.8	7.6	7.8	6.7	7.6	7.6	7.7	7.4	7.7	8	7.9	7
80-100	6.9	6.9	7.9	8.2	9	7.8	7.8	7.8	7.6	7.6	8	8	7.6
100-120	7.5	7.2	8.1	8.3	8.8	8.2	7.9	7.9	7.6	7.4	7.9	8	8.1
120-140	7.7	8	8.2	8.4	8.1	8.8		7.9	7.7	7.5	8	7.8	8.3
140-160	7.7	8.2	8.5	9.5	9	8.8	8.4	8	7.8	7.4	7.9	7.9	8.6
Depth (cm)	**4-1**	**4-2**	**4-3**	**4-4**	**4-5**	**4-6**	**4-7**	**4-8**	**4-9**	**4-10**	**4-11**	**4-12**	**4-13**
0-20	7.4	7	7.6	7.7	7.5	7	7.5	7.5	7.5	7.5	7.2	7.4	7.5
20-40	6.6	7.5	7.5	7.6	7.6	6.3	7.5	7.4	7.4	7.4	7.3	7.1	7.2
40-60	6.3	7.3	7.3	7.7	7.5	6.4	7.5	7.4	7.4	7.5	7.3	7.2	7
60-80	6.7	7.1	7.3	7.6	7.3	7.2	7.5	7.4	7.3	7.7	7.7	7.4	7.7
80-100	7.5	7.7	7.8	7.9		7.9	7.7	7.6	6.8	7.8	7.6	7.4	8
100-120	7.9	8	7.8	7.9	8.3	8.2	7.8	7.7	6.6	7.6	7.4	7.5	8
120-140	8.4	8.5	8.4	7.9	8.3	8.8	7.8	7.8	6.7	7.6	7.1	7.1	8.4
140-160	8.7	9.1	9	8.2	9.5	9	7.7	7.8	7.2	7.7	7.1	7.3	8.4

Average across all transects													
Depth (cm)	**Tube 1**	**Tube 2**	**Tube 3**	**Tube 4**	**Tube 5**	**Tube 6**	**Tube 7**	**Tube 8**	**Tube 9**	**Tube 10**	**Tube 11**	**Tube 12**	**Tube 13**
0-20	7.5	7.4	7.6	7.7	7.6	7.3	7.6	7.6	7.6	7.3	7.5	7.4	7.8
20-40	7.1	7.4	7.4	7.5	7.4	7.2	7.5	7.5	7.4	7.0	7.5	7.4	7.2
40-60	7.0	7.1	7.3	7.7	7.1	7.2	7.6	7.4	7.4	7.4	7.6	7.5	7.2
60-80	7.0	6.9	7.1	7.7	7.4	7.5	7.6	7.4	7.5	7.5	7.8	7.8	7.5
80-100	7.4	7.5	7.5	8.1	8.4	8.0	7.8	7.6	7.5	7.6	7.7	7.8	8.0
100-120	7.8	7.7	7.6	8.3	8.5	8.6	7.9	7.8	7.5	7.6	7.7	7.8	8.3
120-140	8.1	8.1	8.0	8.3	8.4	8.9	7.9	7.8	7.6	7.6	7.6	7.8	8.3
140-160	8.3	8.4	8.2	8.7	9.1	9.0	8.1	7.9	7.7	7.7	7.6	7.9	8.5

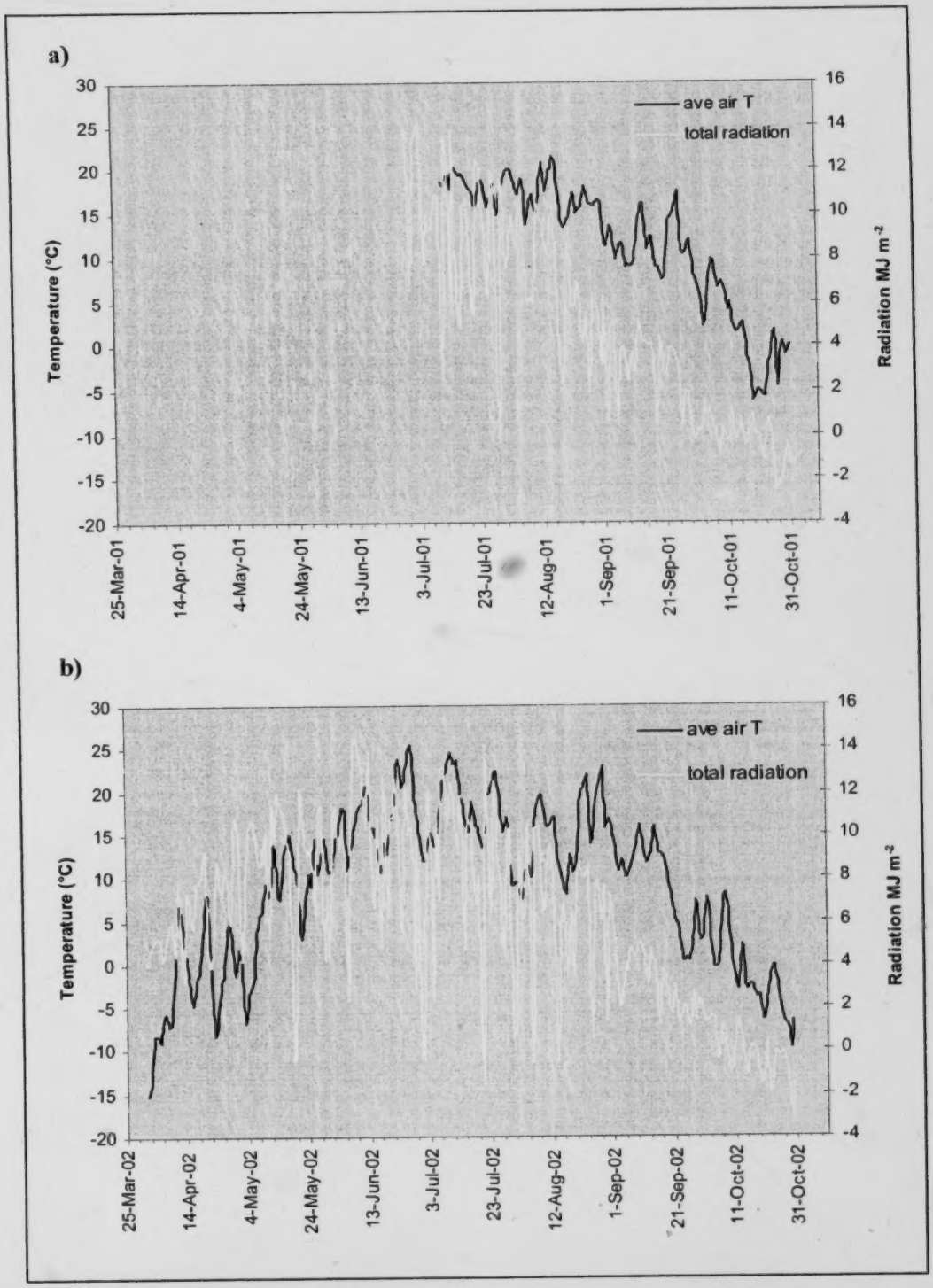

Figure 6.1 Average air temperature and solar radiation on the instrumented watershed
a) 2001 field season (data set starts in July) b) 2002 field season

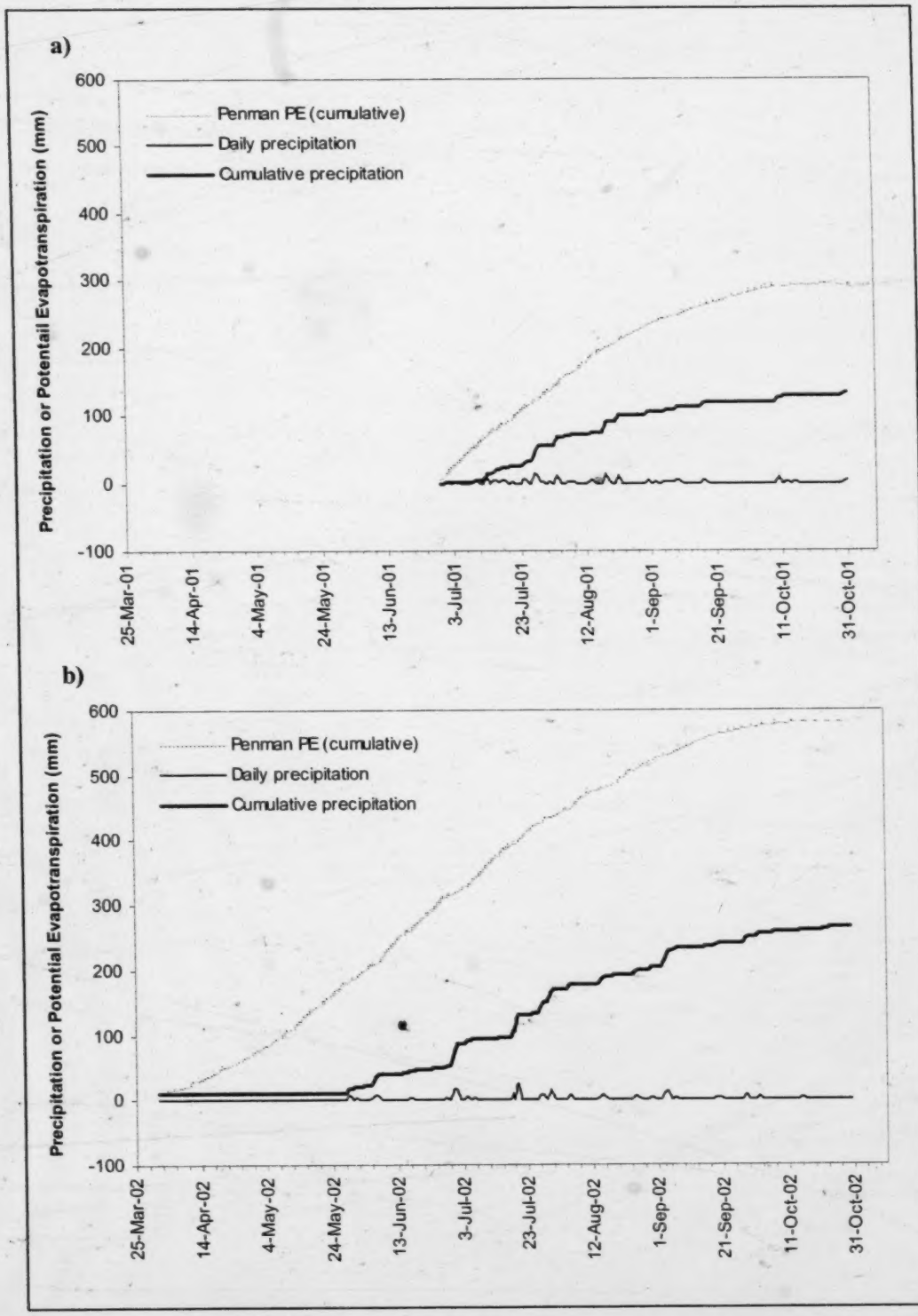

Figure 6.2 Precipitation and evaporation on the instrumented watershed
a) 2001 field season (data set starts in July) b) 2002 field season

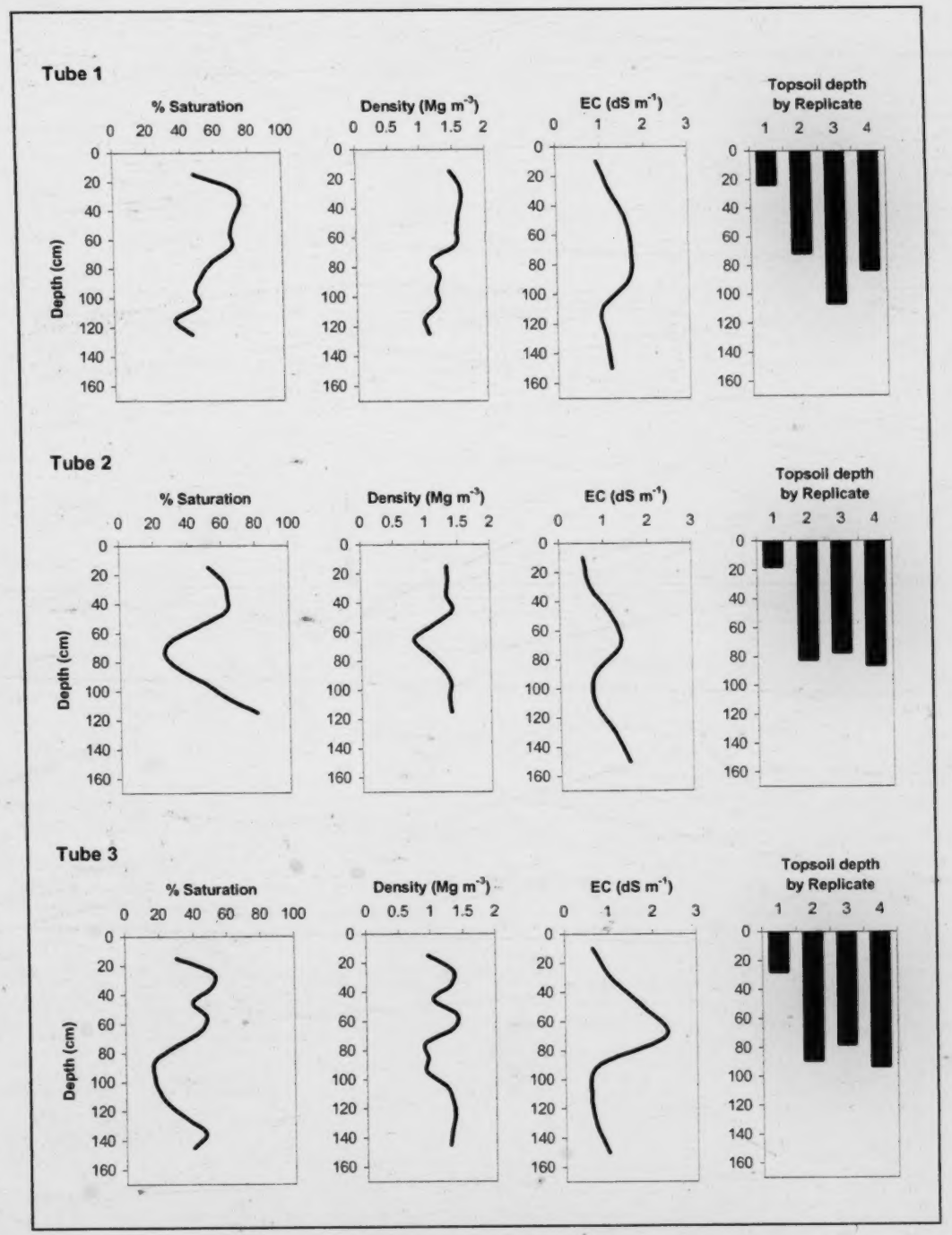

Figure 6.3 Comparison of major soil parameters by tube location
All averaged across four replicates (except topsoil depth).
Percent saturation shown for June 9, 2001 (wettest day), bulk density measured on August 27, 2002, EC measured on July 24, 2001.

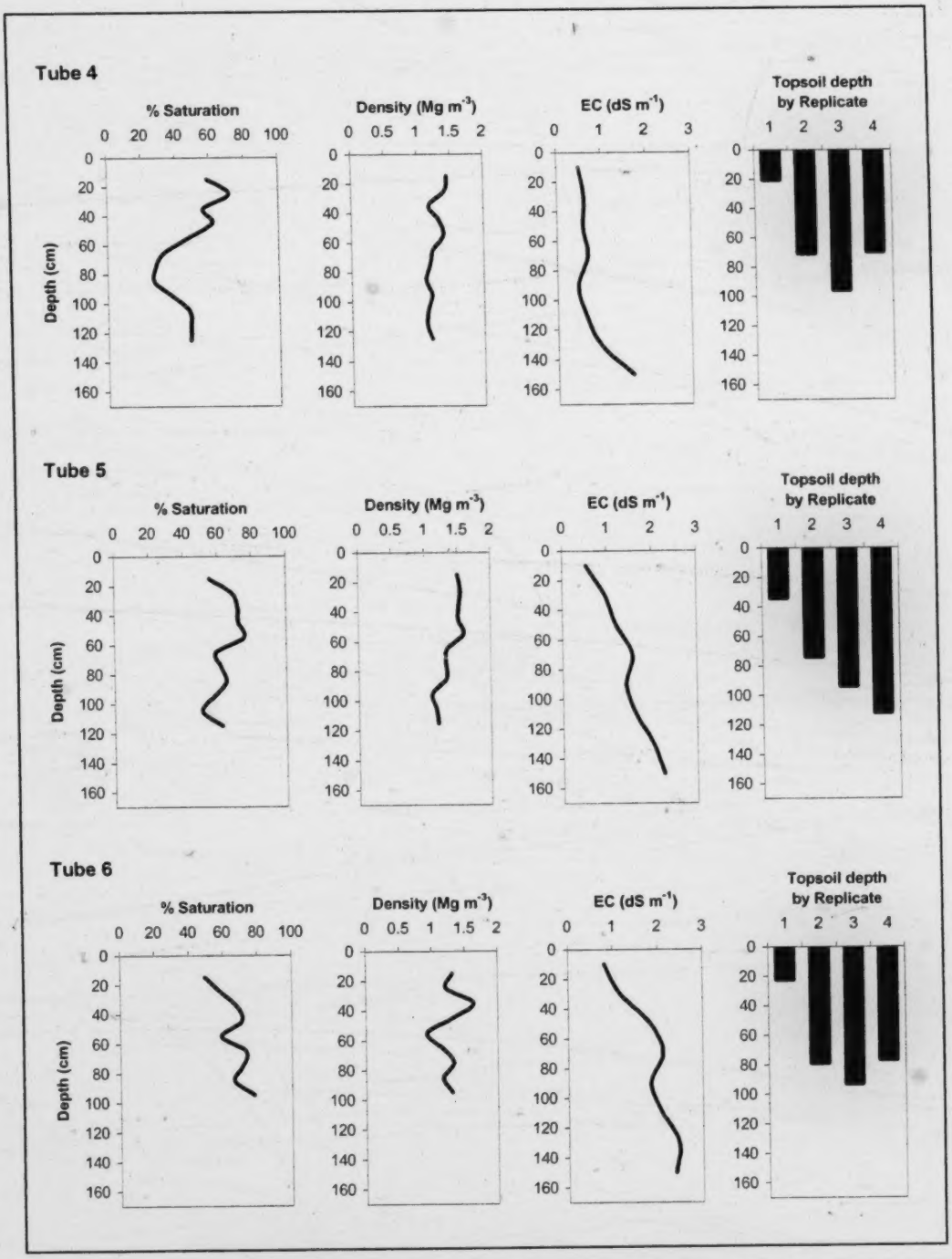

Figure 6.3 (continued) Comparison of major soil parameters by tube location
All averaged across four replicates (except topsoil depth).
Percent saturation shown for June 9, 2001 (wettest day), bulk density measured on August 27, 2002, EC measured on July 24, 2001.

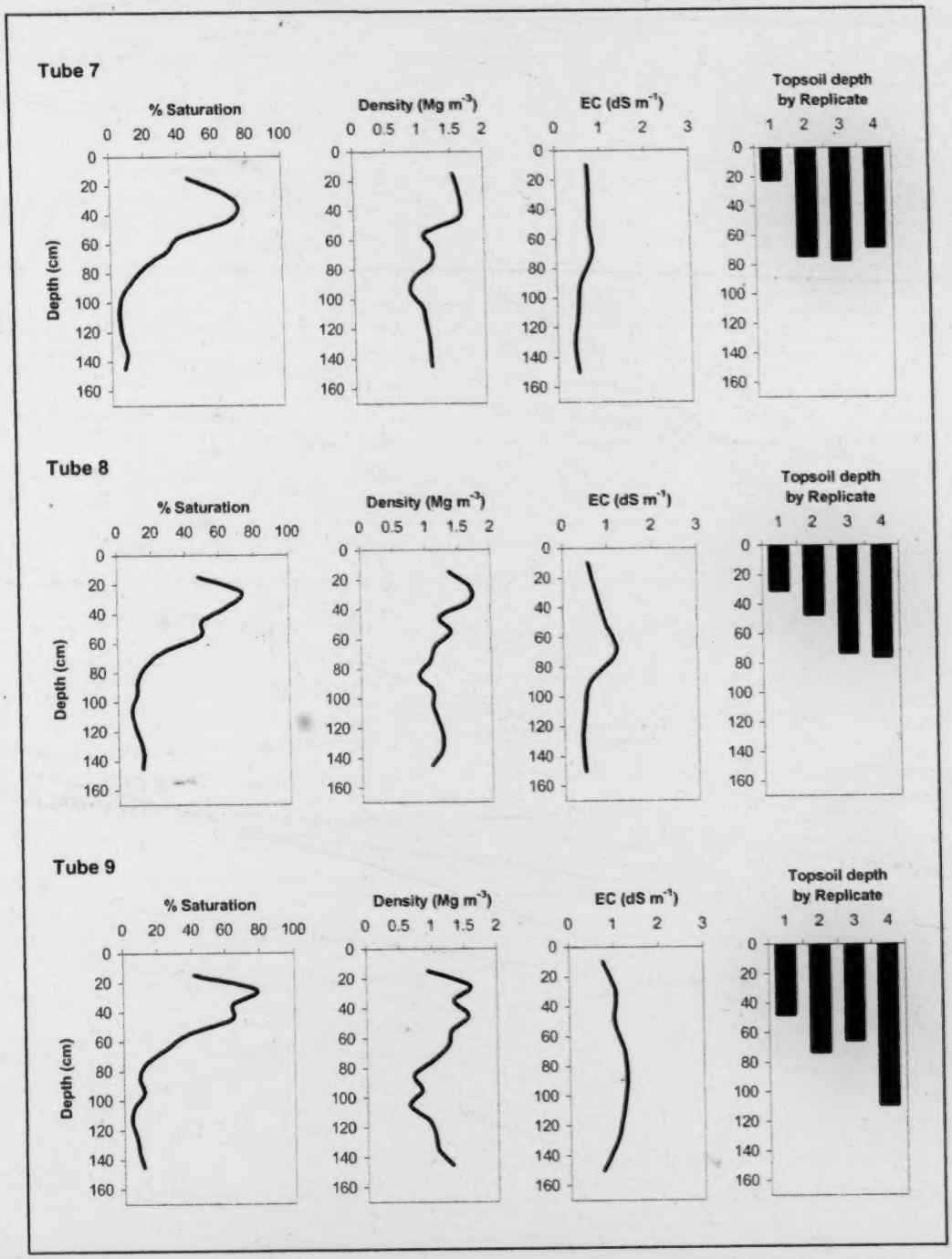

Figure 6.3 (continued) Comparison of major soil parameters by tube location
All averaged across four replicates (except topsoil depth).
Percent saturation shown for June 9, 2001 (wettest day), bulk density measured on August 27, 2002, EC measured on July 24, 2001.

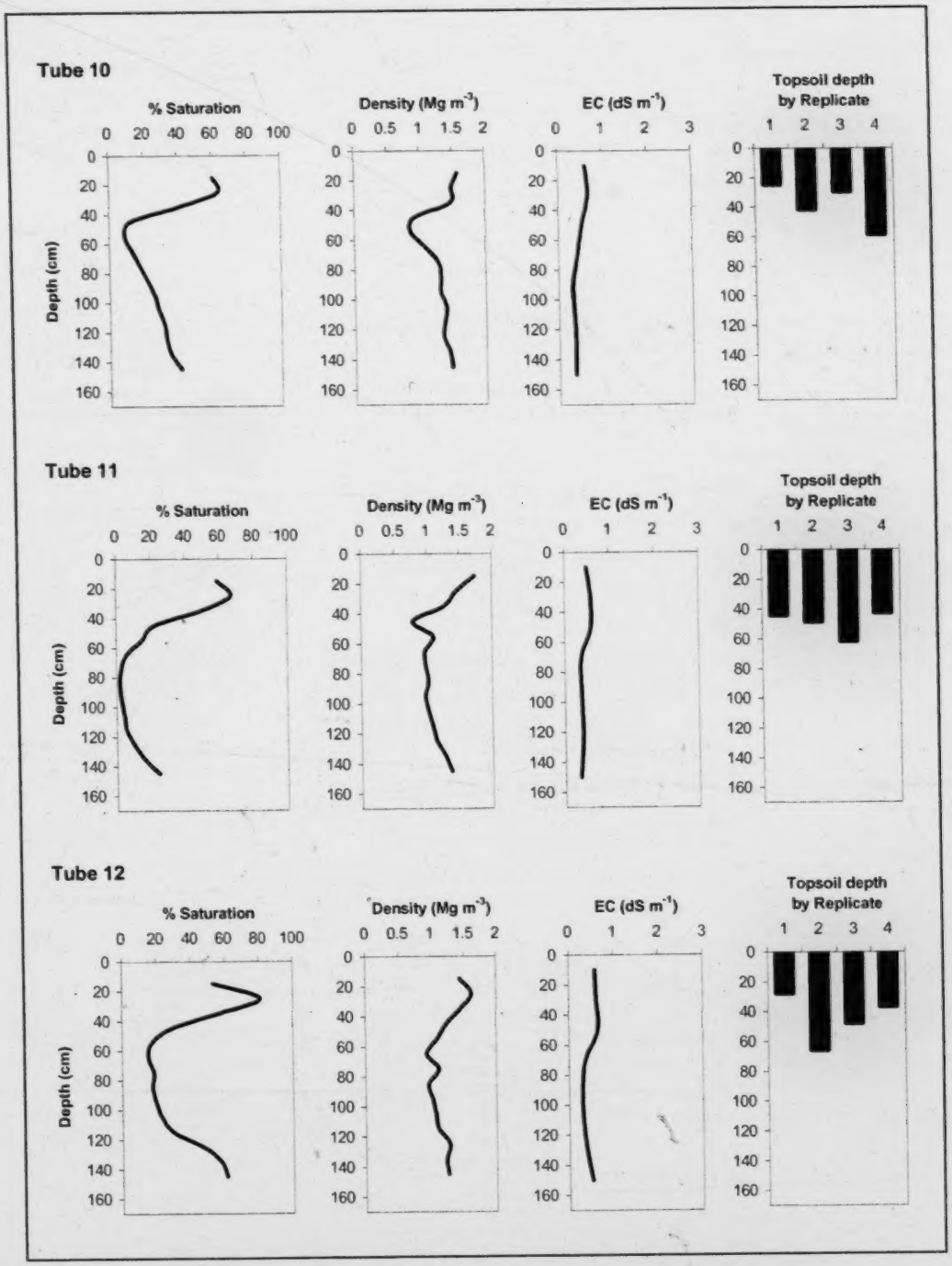

Figure 6.3 (continued) Comparison of major soil parameters by tube location
All averaged across four replicates (except topsoil depth).
Percent saturation shown for June 9, 2001 (wettest day), bulk density measured on August 27, 2002, EC measured on July 24, 2001.

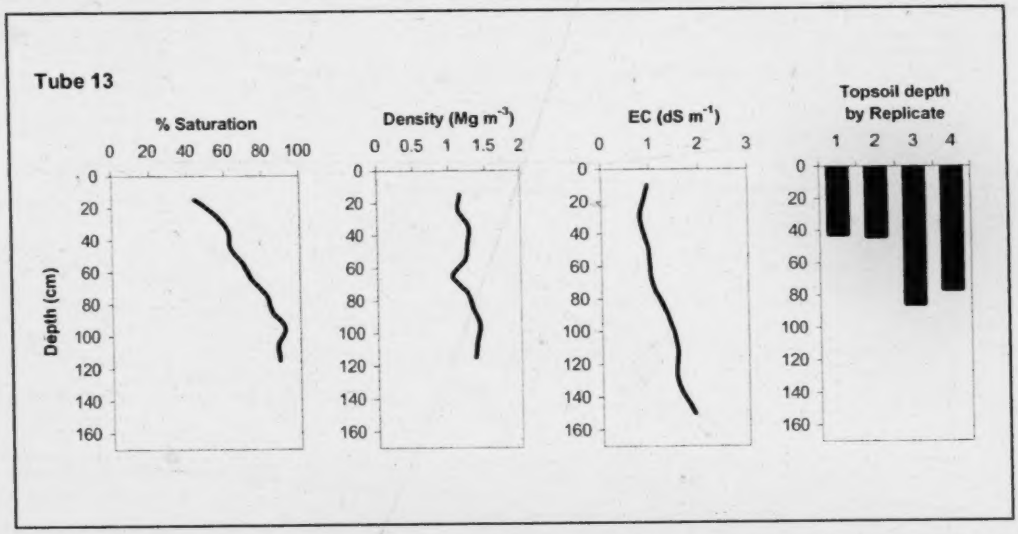
Tube 13
% Saturation
0 20 40 60 80 100
Density (Mg m-3)
0 0.5 1 1.5 2
EC (dS m-1)
0 1 2 3
Topsoil depth by Replicate
1 2 3 4
Depth (cm)
0 20 40 60 80 100 120 140 160

Figure 6.3 (continued) Comparison of major soil parameters by tube location
All averaged across four replicates (except topsoil depth).
Percent saturation shown for June 9, 2001 (wettest day), bulk density measured on August 27, 2002, EC measured on July 24, 2001.

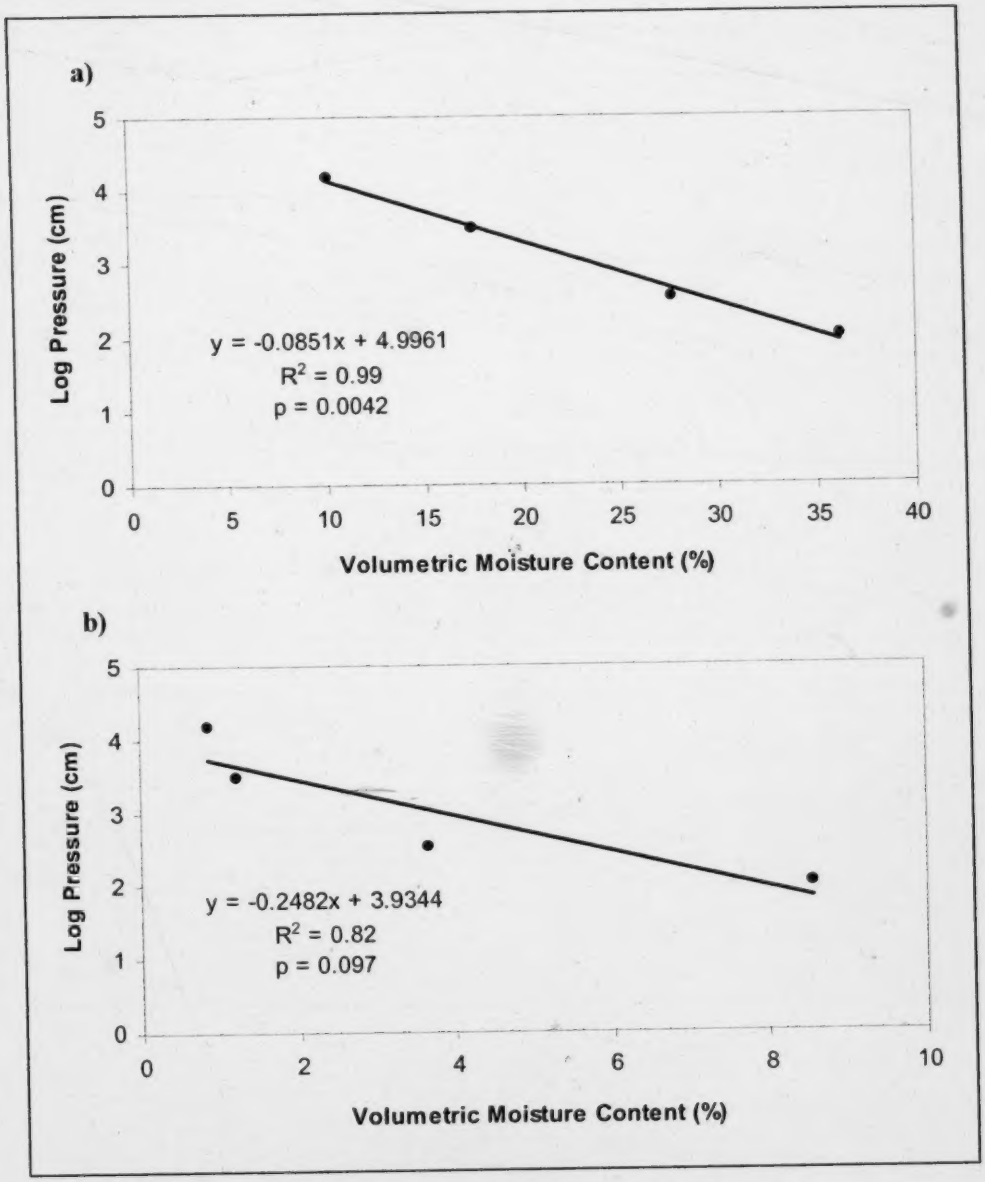

Figure 6.4 **Soil moisture characteristic curves (pF scale graphs)**
a) topsoil and b) tailings sand